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FOUNDED 1854.

CIVIL & MECHANICAL
ENGINEERS' SOCIETY
ESTABLISHED 1859,

AMALGAMATED

· AND ·

* INCORPORATED 1910 *

Norman Scorgie, M.Inst.C.E.,

President of The Society of Engineers (Incorporated) for the year 1915.

(See page 5.)

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COUNCIL AND OFFICERS FOR 1915.

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THE INSTITUTION OF ELECTRICAL ENGINEERS.
VICTORIA EMBANKMENT, W.C.

NORMAN SCORGIE,

President of The Society of Engineers (Incorporated) for the year 1915.

In 1878, Mr. Scorgie was articled to Mr. Richard Read, Assoc.M.Inst.C.E., City and Waterworks Engineer of Gloucester, for a period of three years, and at the expiration of his pupilage was appointed Assistant to him.

In 1883 he was appointed by the Corporation of the Borough of Leicester one of the Assistant Engineers under the Borough Engineer, the late Mr. Joseph Gordon, M.Inst.C.E., who, at the time of his death in 1889, was the Chief Engineer to the London County Council. In 1887, he was promoted to the position of Resident Engineer upon the Flood Prevention Works, superintending the construction of a new circular weir 500 feet long, with lock, flood basins, retaining and towing path walls, new canal and flood channel, &c., work entailing an expenditure of over £50,000.

In 1888 he was further promoted and appointed Chief Engineering Assistant to Mr. Gordon, and Assistant Engineer on the Main Drainage Works, amongst other important work ; assisted in the design and superintended the construction of over nine miles of main sewers costing over £100,000, and continued in the same capacity to Mr. E. George Mawbey, M.Inst.C.E. (who succeeded Mr. Gordon) until 1893, when he was appointed Engineer and Surveyor to the Vestry of Rotherhithe (now part of the Borough of Bermondsey).

In 1899 he was appointed Chief Engineer and Surveyor to the Vestry of Hackney, and when the Local Government Act came into force in 1900, he was unanimously re-appointed Borough Engineer and Surveyor, which appointment he still holds.

Mr. Scorgie was admitted a Student of the Institution of Civil Engineers in 1881, elected an Associate Member in 1889, and transferred to the class of Member in 1901. He is also a Member of Council of the Institution of Municipal and County Engineers. Joined the old Society of Engineers in 1891, and was elected to the Council in 1909.

LIGHTHOUSE DESIGN AND CONSTRUCTION.

By Louis S. Spiro (Associate).

The difficulties which had to be overcome in the construction of certain lighthouses have caused some of them to rank among the best specimens of engineering skill. The subject is, therefore, instructive and interesting both from an engineering and from an historical point of view.

1. History.—The most famous of ancient lighthouses was the Pharos of Alexandria, known as Ras-el-Tin Lighthouse. It was built by Sostratus of Cindus for Ptolemy II. (283-24 B.C.), and was one of the seven wonders of the world. All traces of this tower (said to have been 600ft. high) have now disappeared, the present structure, which is 180ft. above high water, dating from 1848. The tower at Aetia was built by the Emperor Claudian in 50 A.D., and other noted lighthouses of the Romans were those at Ravenna, Pozzuoli and Messina.

The earliest lighthouses in Western Europe were those at Boulogne (Le Tour d'Ordre) and at Dover (the Pharos), built by the Romans. The lighthouse of Cordonan, built on a rock in the sea at the mouth of the Gironde, is the earliest example of a tower exposed to the onslaught of the waves. During the 17th and 18th centuries many towers with braziers were built at various places on the coasts of Europe, such as those at Tynemouth (c. 1608), St. Bees (1718), and the Lizard (1751). The Eddystone lighthouse was originally designed by Smeaton in 1759, and rebuilt by Sir James N. Douglass in 1878-82. Previous lighthouses on this site were built by Winstanley (1698-1703) and Rudyard (1709-55). The Bell Rock lighthouse was built by R. Stevenson (1708-10).

The oldest lighthouse in the United States is the Boston lighthouse on little Brewster Island, Massachusetts, which dates from 1716, the present structure dating from 1859. Other early lighthouses were at Beaver Tail, near New Port (1740), and at Brandt, in Nantucket Harbour (1754).

The credit of the various reforms in lighthouse construction and illumination may be chiefly attributed to Thomas Stevenson, Sir James Chance, Dr. John Hopkinson, F.R.S., and Sir James N. Douglass, in England; and to A. Fresnel, M. Argand, M. Carcel, and D. Arago, in France. To the first is due the great improvement in luminous power produced by the Holophotal system described later. To the second the perfecting of the Catadioptric or totally reflecting glass mirror, which had been originated by Thomas Stevenson. Sir J. Chance perfected this

system, and generated the zones round the vertical instead of the horizontal axis, separating them, and dividing them into segments. Dr. J. Hopkinson introduced the group flashing system, while Sir James N. Douglass designed many lighthouses and carried out useful experiments on lighthouse illumination and fog signalling.

Fresnel, the illustrious French engineer, was the first to carry out the idea of the "lentille à échelons," or the "lens in steps," as well as glass apparatus for fixed lights. He also contrived methods of economically grinding such lenses and prisms with precision. To M. Argand we are indebted for the admirable invention which bears his name, an oil lamp with a tubular wick occupying the annular space between two metallic tubes. The Carcel lamp has been selected as a standard to which, in France, photometric determinations are referred. D. Arago assisted Biot in measuring an arc of the meridian, and confirmed the undulatory theory of light (1816).

II. SUPERSTRUCTURE.—Lighthouses built on shore do not present great difficulties in construction, but those erected on rocks or reefs exposed to the sea vary considerably in design. They may be built of :—

(*a*) Masonry or concrete where the foundation is good. The masonry is built up in a solid mass, and should be of granite where possible. The upper apartments are usually formed with an arched roof, the side-thrust of which is counteracted by iron chains surrounding the tower. These chains, which are bedded in lead, are placed in position while hot, and by their contraction bind the structure together strongly. The light room may be of any shape, but is usually octagonal or circular, and consists of an iron framework, glazed with thick plate glass.

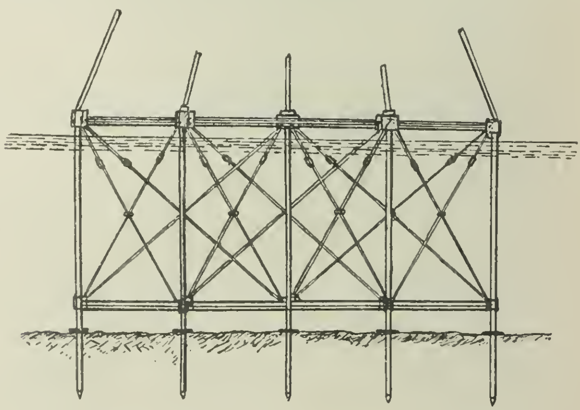


FIG. 1.—LIGHTHOUSE FOUNDATION ON PILES.

(*b*) An iron or steel framework on pile foundations is suitable for shoals, coral reefs, etc., where a rock foundation is not found at a suitable depth. (See Fig. 1.)

(*c*) A structure covered with cast or wrought iron or steel plates for situations where the cost of stone or the scarcity of labour renders masonry expensive. Such lighthouses should be made circular, and are usually supported by a tripod composed of cast iron columns with struts and diagonal bracings. They are easily and quickly erected at a cost of about one-third of stone towers of the same altitude, are strong enough to bear shocks and vibrations, and are fire-resisting. Among notable examples of such towers are those on Dassen Island (South Africa) and Tasman Island (Tasmania).

In designing a lighthouse tower careful measurements must be made of the velocity and height of the greatest waves, the depth of water, and the force of the wind, such data to form a basis for calculations. A wave 30ft. high may exert a pressure of nearly 1 ton per sq. ft. of surface, while in exposed positions and in deep waters $1\frac{2}{3}$ tons per sq. ft. may be exerted by waves striking suddenly on a vertical surface. Measurements made at Skerryvore showed that the force of waves was sometimes equivalent to a pressure of 4,335 lb. or nearly 2 tons per sq. ft. As in the case of chimneys, the tower should be built to stand a wind pressure of at least 56 lb. per sq. ft. The force of winds and waves is usually opposed by the weight of the structure itself.

III. Foundations.—The distribution of the weight of the tower upon the foundation is of the utmost importance. A suitable surface for the foundations is all that need be prepared in hard rock. If the soil is loose some method of piling is usually adopted ; cross pieces are used to connect the piles, and the whole framework is set in concrete.

Caissons are used in laying subaqueous foundations under towers and consist of cast iron cylinders sunk into solid strata. When the caisson has sunk to the required depth it is filled with concrete. The excavation in the caisson is usually carried on under compressed air.

Caisson foundations are used where a substantial structure is erected on sandbanks, shoals, etc. The Rothersand tower, which was commenced in May, 1881, and destroyed in October of the same year, is an example. The present structure was completed in 1885 ; is 78ft. above high water, and 185ft. from the foundation caisson to the top vane. Sangareb lighthouse, in the Red Sea, has a caisson foundation.

Important points relating to foundations are :—

(1) The structure should preferably be circular in plan, but may be hexagonal or octagonal. Port Said lighthouse, one of the best in the Mediterranean, is octagonal.

(2) The centre of gravity of the tower should be as low and the foundation as deep as possible.

(3) The lower portion should present a vertical face to the waves, and the upper surface should either have a uniform batter or be continuously curved in the vertical plane.

(4) There should be no projections in the tower except a gallery under the lantern, the height of which should be sufficient to prevent the highest spray reaching it.

(5) The stones forming the lower courses should be joggled or dovetailed into the rock itself and into each other.

IV. SYSTEMS OF SHOWING LIGHTS.—Lights may be classified as fixed, flashing and occulting, the other lights referred to herein really coming within the last two classes.

(*a*) *Fixed Lights.*—When the rays from the source of light are distributed horizontally in every direction, being condensed only in the vertical plane, the light is a "fixed light." Fixed lights are now very little used, being converted into occulting lights in many cases by the use of apparatus which enables the light to be cut off when required. When so converted they show revolving or intermittent characteristics over certain areas, the differences being effected by masks arranged like Venetian blinds. Fig. 2 shows a fixed light of 180°.

(*b*) *Flashing Lights.*—When the rays are concentrated into a pencil or cone of light directed towards the horizon and caused to revolve round the source of light, the light is a flashing light. All lights in which the period of darkness exceeds that of light are also termed flashing. For "sector lights" and those throwing a beam over a wider azimuth than the flashing lights the rays are condensed both in the vertical and horizontal plane in such a manner as to concentrate the light over an azimuth of the required magnitude.

Flashing lights are further divided into "group flashing," where two or more flashes are followed by an eclipse of some

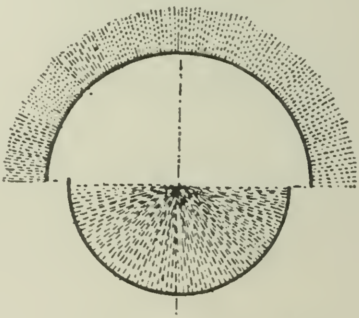


FIG. 2.– FIXED LIGHT AND DIOPTRIC MIRROR OF 1800.

seconds; "fixed and flashing," "fixed and group flashing," according to the duration and combination of light and darkness. Quick-flashing lights, or "feux éclaires," are those in which the duration of the flash is short, being reduced with advantage to 3-10ths of a second, and the flashes are made to succeed each other in quick succession, so that the mariner may be enabled to take his bearings from succeeding flashes instead of from a single one. The first light on this system was made in 1893, and was supplied to the Imperial Maritime Customs in China. (See Figs. 2 to 7.)

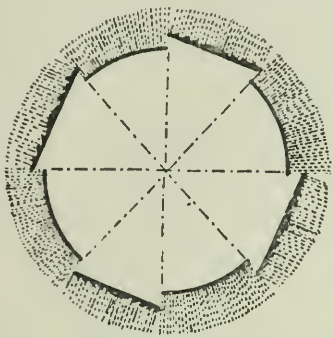


FIG. 3.—FIXED AND FLASHING LIGHT.

(*c*) *Occulting Lights* are those in which the light period is longer than the dark, the period of occultation being arranged as required. The distinction between the occulting and flashing light is simply one of duration. "Group occulting" has groups of two or three eclipses made at intervals by revolving screens regulated by occulting clocks. Where gas is the illuminant the occultations may be produced by a clock operating a gas valve on the supply pipe. Such clocks have been constructed to run for one month without rewinding, and besides producing the occultations they open the gas valve at night and close it in the morning, and are also arranged to vary automatically the time of lighting up and extinguishing according to the season of the year.

(*d*) *Intermittent lights* are those which are suddenly turned on and off at fixed intervals. There are intermittent lights of unequal periods, for instance, fixed for 2 seconds, eclipsed for 5, fixed for 2, eclipsed for 2, and then fixed for 2, eclipsed for 5, and so on. The intermittent flashing light shows a succession of quick flashes followed by a dark interval. The effect is produced by the motion of shades in front of reflectors, alternately displaying and hiding the light.

(e) *Revolving Lights.*—A revolving light is produced by the revolution of a frame with three or four sides, having reflectors of a larger size than those used for a fixed light, grouped on each side with their axes parallel. The revolution exhibits once in one or two minutes, as may be required, a light gradually increasing from eclipse to full strength, and then decreasing to total darkness.

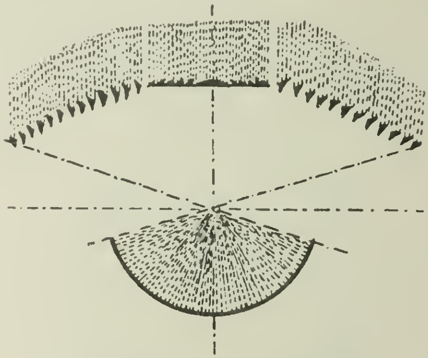


FIG. 4.—SINGLE FLASHING LIGHT.

The regular appearances and eclipses of light prevent the mariner from mistaking for a lighthouse a bright star near the horizon. Further, to characterise each lighthouse, a different period of revolution may be given to each one on a particular coast.

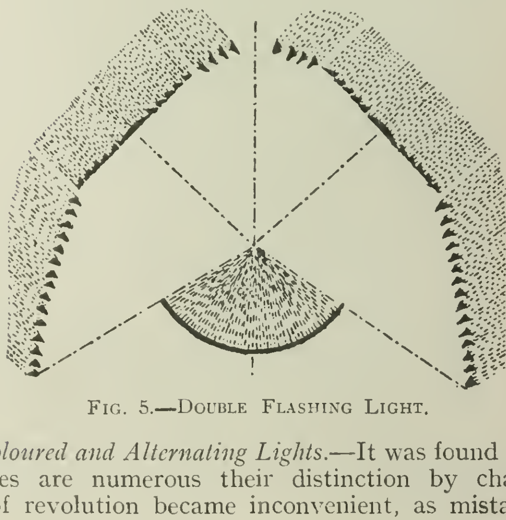


FIG. 5.—DOUBLE FLASHING LIGHT.

(*f*) *Coloured and Alternating Lights.*—It was found that where lighthouses are numerous their distinction by characteristic periods of revolution became inconvenient, as mistakes might

easily be made in small differences of time, and it would be inexpedient to keep a long interval of darkness. Hence the addition was made of red lights or lights alternately red and white. Coloured lights, however, seem to be falling into disuse because coloured rays travel with a lower velocity than white rays. A system of augmented light has, therefore, to be used to make the coloured ray equal in visibility to the alternate white rays. An alternating light is one in which different colours are shown alternately without an interval.

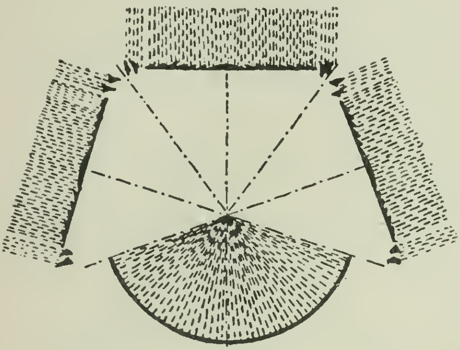


FIG. 6.—TRIPLE FLASHING LIGHT.

V. LUMINOUS POWER.—The illumination of a body depends on the distance between it and the source of light and on the quantity of light given by the source. The intensity of illumination of the body varies inversely as the square of the distance of the point from the light. Therefore, by so adjusting the distances of two sources of light that they give equal illumination on a surface, their comparative power is arrived at. The eye fails to make even an approximation to a scientific comparison of the power of two sources of light, but it can recognise equal intensity of illumination. In lighthouses the question is one of visibility, which depends on the power of penetration of the light and the height of the tower above sea level. The penetration varies with the quality of the light and the transparency of the atmosphere. By the introduction of the Holophotal light it has been found unnecessary to carry lighthouses to a height greater than about 180ft. Taking the curvature of the earth into consideration, the greatest distance at which such a light is visible will be found to exceed by far the distance calculated for the given height. With regard to the transparency of the atmosphere, a series of observations has been made by the "Depôt des Phares," in France, to estimate the transmission through the atmosphere under different conditions, both in the Mediterranean and the Atlantic coasts.

The light of gas buoy lamps was observed with the following results :—

Colour of Light.	Intensity in Carcel Burners.	Distance of transmission of the light according to the condition of the atmosphere.					
		Hazy.		Medium.		Clear	Complete transparency
		Atlantic Ocean.	Mediterranean.	Atlantic Ocean.	Mediterranean.	Atlantic and Mediterranean.	
White ...	8·00	4·52	6·71	7·51	8·41	10·81	15·12
Red ...	1·60	3·02	4·12	4·47	4·84	5·69	7·00
Green ...	1·00	2·64	3·51	3·78	4·05	4·65	5·40

It will be seen from the above that the distance of penetration of white light varied from 4 to 15 miles, the maximum being attained only in the exceptional conditions where the atmosphere was completely transparent. It is also interesting to note that the atmosphere is more transparent in the Mediterranean than in the Atlantic coast. An idea may also be formed of the relative power of the coloured lights used.

VI. Systems of Lighting.—The light from a luminous body spreads out from it in all directions equally, so that if it is placed on a tower few of the luminous rays benefit the mariner, namely, only those which are directed to the horizon. All the light which passes landwards would be entirely lost for our purpose, a much larger portion would stream upwards and be lost in space, another part would descend towards the base of the tower and be equally wasted. Even in the case of an isolated lighthouse, if all the light is sent out in a nearly horizontal plane to the horizon, the intensity of the illumination will diminish on account of the widening space as the distance increases. The problem is, therefore, to send the whole of the light in one unbroken beam so that the only loss it can experience may be the absorption by the imperfectly transparent atmosphere. There are two means of gathering up all the beams and sending them in such a direction as to reach the eye of a distant mariner. One method is by reflection from mirrors where only metal is used, and is called catoptric, and the other by refraction through lenses, and is called dioptric. The systems employed are as follows :—

(*a*) *Catoptric Reflection.*—We read of cases in which screens of sheet brass were placed on the landward side to throw the light seaward. This system dates from about 1763, but the first application of scientific lighting principles was in the parabolic reflector of Hutchinson of Liverpool, in 1777. The parabolic reflector used in France for the first time was at the Tour de

Cordonan in 1780. The brightest part of the light represented the focus of the parabola and the silvered mirror reflector was shaped like the inside of a saucer, but formed of a number of plane facets. The rays are reflected from the facets in a direction parallel to the axis, thus forming a cylindrical beam which is visible at a great distance. The focus being merely a point, whereas the flame has a certain magnitude, it follows that the want of coincidence of the other luminous points with the focus produces a certain divergence in the reflected rays, so that the beam is not accurately cylindrical, but it has the effect of slightly widening the strip of sea illuminated by the beam. This was remedied by the other systems described further on.

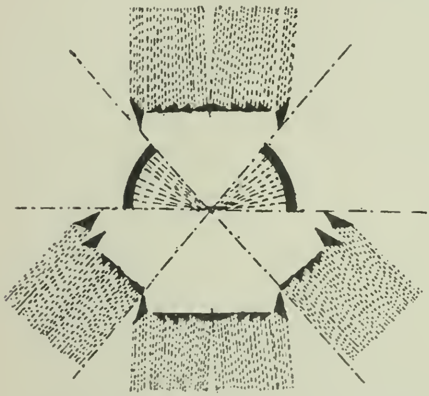


FIG. 7.—SINGLE FLASH FOLLOWED BY TRIPLE FLASH.

The catoptric system was further applied to lights that were intended to show all round the horizon. This was effected by fixing a number of parabolic reflectors round the light. Then it was found that by having a number of reflectors the light could not be equalised over the whole horizon. There was always a darker interval between the concentrated rays of each reflector. For example, if eight reflectors were so placed, eight beams of light would stream out like eight spokes of a wheel, and eight sectors would be left unilluminated, and for ships in these spaces the lighthouse would be virtually non-existent. To distribute the light equally round the horizon a light was devised by M. Bordier Marcet in 1819. This light had two reflectors of parabolic pattern, formed by revolving a parabola horizontally round a vertical axis passing through its perimeter. The same light represented the focus of each, and the beams swept over the whole expanse of the waters, and thus for every ship the light was visible for an instant.

The efficiency of reflectors depends on the state of polish of

the surface, and even with the most brilliant polish there is a very large loss of light. In the ordinary condition of lighthouse reflectors it is found that about one-half of the light is lost at the surface of the mirror. Moreover, the polish of the metal is very readily destroyed, and as it is constantly liable to be tarnished, the frequent cleaning required is apt to produce a scratched state.

There is a form of mirror coated with a non-tarnishable metal manufactured by a patent process, and another form which is not rendered useless if struck by a bullet. The latter type is employed by the Admiralty and War Offices.

(*b*) *Dioptric Refraction.*—An attempt was made in England about the beginning of the 19th century to substitute glass lenses for mirrors, but it was found that in spite of the loss occurring in reflection, the mirror produced a more intense beam. Fresnel solved the problem by giving the lenses a short focal length with large diameters. The dimensions required by these conditions far exceeded any that could be given to lenses formed in the ordinary manner, the great thickness of glass diminished the transparency and unduly increased the weight of the apparatus. Therefore the system fell into disfavour owing to these and other mechanical difficulties in the construction and arrangement of the lenses. In 1822 and the following years Fresnel introduced annular lenses which had been previously used for heat only and not for light. The lenses were cut in rings with a common centre, and were like steps ascending one from another, which he called "lentille à échelons," or the "lens in steps." This was the first advance in the direction of dioptric illumination, the rays pass through the lenses and are refracted at the incident and emergent faces. The construction of the annular lenses will be readily understood from Fig. 8, where *a b* is a

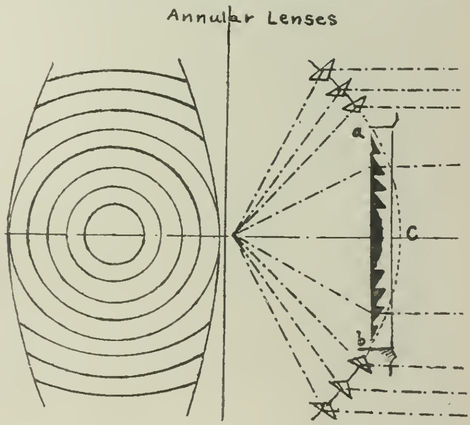


FIG. 8.— ANNULAR LENSES.

section of a lens in steps and the dotted line *c* shows the thickness of an ordinary lens of the diameter *a b* would have. Fresnel kept only the marginal part of the lens ; and inside of the ring formed by this he fitted the margin of a second large lens having the same focal distance ; inside of this another ring, and so on, and in the centre a large lens of moderate thickness.

His next development was the cylindrical refractor, which consists of a glass cylinder, the face of which was cut all round after the manner of his first annular lens, the flame being in the centre. This distributed the light all round, not in one direction only.

Prisms giving total reflection, which Fresnel finally produced, consisted of glass cut on an improved pattern, so that each ray was reflected once and refracted twice in a horizontal direction. In another design he effected further great improvements, and made his glass refractors (instead of Marcet's metal reflectors) the primary light-directing devices. Thus the apparatus was entirely constructed of prisms giving total reflection, which arrangement is still the basis of lighthouse illumination all over the world.

(*c*) *Catadioptric System.*—This system dates from 1823, and is a combination of the other two, the light rays being refracted at the incident face, are totally reflected internally at the second face, and are again refracted on emergence at the third face.

(*d*) *Stevenson's Holophotal Light*, 1835.—A name applied to such form of lighting apparatus as would utilise the whole of the available light by subjecting it all to the collective action of the instrument. The Holophotal light of Allan Stevenson will form the most intense beam that a given source of illumination can yield. It will be interesting to note that the Holophotal light at Baccalieu, in Newfoundland, is visible in clear weather from a point 40 miles distant. So long a range as this is seldom possible at sea on account of the curvature of the earth rendering it necessary to raise the light nearly 1,000ft. above the water level if it is required to be visible at that distance.

The construction of this apparatus is shown in Fig. 9.

L represents the source of light, A B, A′ B′ a parabolic metallic mirror. All the rays between L A and L B and between L A′ and L B′ falling upon the mirror are reflected parallel to the axis L G. The rays included in the space B L B′ would escape from the mouth of the mirror B B′ as a diverging cone. This is prevented by placing the lens H I, the focus of which is at L, so as to convert the diverging cone I L H into a cylindrical beam E H I F, thus half the light emitted from the luminous point is sent in one direction. A hemispherical reflector C K D receives the other half, which is thrown back through L and follows the same course as the direct rays. Mr. Stevenson afterwards sub-

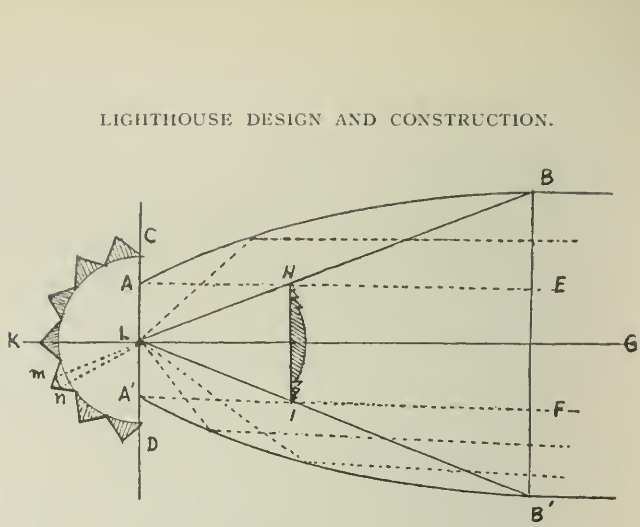


FIG. 9.—STEPHENSON'S HOLOPHOTAL LIGHT.

stituted a system of prismatic glass zones for the metallic reflector C K D. These had the same effect without the loss of light occasioned by the latter. The inner surface of the prism is hemispherical, and the prismatic zones are such as would be produced by turning the section about L K (or C D) as an axis. The dotted line L M shows the course of a ray of light, which, meeting the hemispherical surface perpendicularly, passes straight through it, and is totally reflected at *m* by the inclined surface and again at *n*, returning to L by the path *n* L. Reflecting glass prisms were also substituted for the metallic mirror A B, A′ B′, thus entirely dispensing with the use of metal in this apparatus.

A light may be of the hyper radial type, of the 1st, 2nd, 3rd, 4th, 5th or 6th order, according to the focal length of the lens used, as follows :—

Hyper radial light has a	focal length of		1,330 m/m = 52·363 in.
1st Order light	,,	,,	920 m/m = 36·221in.
2nd ,, ,,	,,	,,	700 m/m = 27·56in.
3rd ,, ,,	,,	,,	500 m/m or 375 m/m = 19·685in. or 14·764 in.
4th ,, ,,	,,	,,	250 m/m = 9·843in.
5th ,, ,,	,,	,,	187·5 m/m = 7·382in.
6th ,, ,,	,,	,,	150 m/m = 5·906in.

The lenses and prisms are usually made of crown glass, and are ground by fixing them on a large revolving iron table, on which they are bedded in plaster of Paris and firmly cemented by pitch, great care being taken to place them in the exact position required, for only about $\frac{1}{8}$in. is allowed for grinding down to shape the glass as it comes from the moulds. Sand, emery, and finally rouge are used with water for the grinding and polishing

processes. The lenses and prisms are very carefully adjusted in their gun-metal framework, and no plan of testing the adjustment has been found more efficient than that of viewing the sea horizon through them from the position which the flame will occupy.

To form an idea of the extreme accuracy with which some lenses are manufactured it may be mentioned that the polishing of the lens surfaces is checked optically to 1-500,000th of an inch, the highest accuracy humanly attainable. This is done by comparing the glass in course of manufacture with a standard glass template. Between the pair of glasses wide rings of the spectrum colours are seen, and by judging the colour and number of these rings, the glass can be so polished that at no point does the departure from the standard exceed a half-millionth of an inch.

VII. Illuminating Agents.—From very ancient times towers were erected with beacon fires, the first which was regularly maintained for the benefit of mariners being probably that referred to by the Greek poet Lesches at Sigeum in the Troad (now Cape Inchisari). The Pharos of Alexandria, in the reign of Ptolemy II. displayed the light of torches or fires through the upper windows to guide vessels into the harbour. The lighthouses of the South Foreland, which were established in 1634, displayed coal fires until 1790, and the lighthouses in the Isle of Man were first illuminated with oil only in 1816. Smeaton introduced tallow candles stuck in a hoop (1759-1877), a means of illumination which would scarcely now be tolerated, even in a booth at a village fair. Oils of vegetable and animal origin have been used in lamps from time immemorial, but the introduction of mineral oil in 1853 brought about a great efficiency. Oil lamps with flat wicks were introduced about 1763, while the invention of the Argand burner in 1784 caused a great improvement. Sperm oil was used at first and later colza oil, and in 1868 a burner was invented which would consume hydrocarbon oils (petroleum, etc.). Incandescent burners to take coal and mineral oil have also been used, while the first installation of electric light for lighthouses was in 1858.

(*a*) *The Argand Lamp*.—An artificial light is produced by bringing a substance (usually some form of carbon) to a state of incandescence. When an oil lamp is burnt, small particles of carbon are produced by the decomposition of the organic substances in the burnt material, and these particles, becoming heated to the point of incandescence, cause the flame to be luminous. Mineral oil is a satisfactory illuminant, and the efficiency of oil lamps owes a great deal to the burner introduced by Argand. The wick takes the form of a hollow cylinder occupying an annular space between two metallic tubes, and a current of air

rises upwards through the inner tube and feeds the interior of the flame with oxygen. This current and the current which supplies the exterior are increased by surrounding the flame with a tall glass chimney, and a contraction of the chimney, just above the flame, aids greatly in distributing the air so as to ensure the complete combustion of the oil. In the original lamp the supply of oil to the flame depended on the capillary attraction in the meshes of the wick. M. Carcel applied clockwork to pump oil continuously into the burner, so that it was maintained at an unvarying level. This arrangement added greatly to the intensity and steadiness of the light.

The power of the Argand lamp as employed in lighthouses is greatly increased by the use of multiple wick burners employing several concentric wicks, the light thus obtainable being twenty-five times greater than that of the single-wick Argand. Between the wicks there are open spaces through which the air obtains access, and the large amount of heat produced by the combustion of so much oil in a small space is partly carried off by the excess of oil, which is made to overflow the burner, about four times the quantity consumed being constantly pumped up into the burner for this purpose. The following table gives the sizes of the burners and the intensity of light in Carcel lamps :—

Order of light.	No. of Wicks.	Diameter in ins.	Intensity of light in Carcel lamps.
1	4	$3\frac{1}{2}$	23
2	3	$2\frac{15}{16}$	15
3	2	$1\frac{3}{4}$	5

The quantity of oil consumed in these lamps is less in proportion than the increase of light. For example, although the four-wick lamp gives 23 times the light of the simple Argand, it consumes only 19 times the quantity of oil.

(*b*) *The Incandescent Lamp.*—Of late years incandescent oil burners have been universally substituted for circular wick burners. The power of the light has been greatly increased by the incandescent system, and there is also a less consumption of oil. The substitution of three-mantle incandescent for six-wick oil burners showed a saving of £21 in the cost of oil per annum, while the substitution of 85 m/m. incandescent for six-wick oil burners effected an economy of £48 per annum.

The fundamental principle of this system is the vaporisation of ordinary petroleum, which is not only cheap and uncongealable by cold, but gives a brilliant white light. All the Egyptian, Red Sea, and Mediterranean lighthouses (with the exception of

that at Port Said) are lighted with petroleum of a flash point not less than 90° F. (Abel close test) Special burners are used for burning oils having a flash point up to 160° F., close test (71° C.). If oil of a lower flash point is used with such burners the resulting candle power will not be so great.

As a rule, mantles with a fine fabric give better illumination than coarse mantles. However, for stations where the keepers are unskilled or where the risk of breakage in transit is great, mantles of stronger texture should be used. The candle power of a mantle decreases after about 150 hours' use, and therefore it is advisable to change them every fortnight. It is also important that mantles should be stored in a dry place, as if they become damp they are liable to break when placed on the burners and the glaze burnt off. Heat tubes may be used with the burners to carry away the products of combustion and to shield the top prisms from the heat of the burners.

(*c*) *Coal Gas* was first used as an illuminant by William Murdoch, of Redruth, in 1779. The early burners were of the "batswing" type, in which a flattened flame was produced by a slit in the end of the burner. Later the "fishtail" flame was produced by causing two jets of gas from two small holes in the burner to impinge upon one another, with the result that a flattening of the flame was produced. Incandescent burners had been tried as early as 1826, but it was not until after Bunsen had introduced his heating burner that they became successful. Coal gas has been used in lighthouses, and found to give a light of great brilliancy and steadiness.

(*d*) *Acetylene.*—Calcium carbide is not combustible in a dry state, and may safely be thrown in a fire without undergoing any change. When brought into contact with water, decomposition commences, the calcium uniting with the oxygen of the water forming lime, and the carbon combining with the hydrogen producing acetylene gas. It is a colourless gas with a most penetrating odour, which is one of its safe points, as a very small leakage would immediately be detected. It burns with a brilliant luminous flame equivalent to about 240 candles for 5 c. ft. of gas consumed, and has not the greenish shade of the incandescent gas light, but its rays are identical with those of sunlight. When burning it does not emit poisonous carbonic oxide or sulphurous compounds. Taking as a standard the light from 66 sperm candles, acetylene gas takes much less oxygen from the air than candles, oil, or coal gas, as will be seen hereunder :—

Sperm candles	38·5 c. ft. of oxgyen.
Paraffin oil	24·9 ,, ,,
London gas	26·1 ,, ,,
Acetylene gas	5·0 ,, ,,

It has been successfully employed in certain lighthouses, on permanent ways and gas buoy lamps, and its quality renders its use also advantageous where colour work has to be done by artificial light.

(*e*) *The Electric Light.*—The advantages of the electric light over gas are many. In gas we are burning a foul distillation from coal and consuming as well as polluting the air. The electric light is far more intense and powerful than any other artificial light. It has been very successfully applied in certain lighthouses, Port Said lighthouse being lighted with a very powerful arc light since the mode of producing steady currents by magneto-electric machines (now superseded by the dynamo electric machines) has come into use. Lights of from 10,000 to 150,000 candle power are employed, the beam of light being very concentrated on account of its being emitted from what is practically a point. These circumstances cause the beams of the electric light to possess greater power of penetrating the atmosphere than those from any other source.

VIII. Revolving Apparatus.—The rotation of the apparatus is produced either by clockwork duly regulated by special sensitive governors, so that a uniform and constant speed is obtained, or, as in most lighthouses, the moving power is given by the descent of a weight attached to a chain or cord wound round a barrel. One train of wheels is connected with the apparatus for regulating the speed, and to this an indicator is attached which registers the speed. There is also a contrivance for maintaining the motion during winding of the clock, or while the weight is being wound up. The use of a revolving carriage with adjustable rollers has practically been superseded by a bath of mercury, which supports the weight of the whole apparatus, thus reducing friction and rotating at a much higher speed than formerly. One of the chief features of this system, known as the "quick-flashing light," is the short duration of the flash. Another marked advantage is that in the case of lights in countries subject to earthquakes the liquid base affords an elastic joint between the optical apparatus and the iron pedestal, which tends to reduce the shock. The introduction of mercury flotation has also considerably reduced the size of clocks, thus giving more available space in the lantern.

1st February, 1915.

ORDINARY MEETING

MR. H. C. H. SHENTON, Past President, in the Chair.

Presentation of Premiums.

The Chairman presented the Premiums awarded by the Council for papers contributed during 1914 as follows :—

The President's Gold Medal to Mr. A. S. E. Ackermann for his paper on " The Utilisation of Solar Energy."

The Bessemer Premium, value £5 5s., to Mr. A. S. Buckle for his paper on " Cylinder Bridge Foundations in the East and the Construction of the Sittang River Bridge, Burma Railways."

The Clarke Premium, value £5 5s., to Mr. S. M. Dodington for his paper on " Mechanical Appliances for the Painless Killing of Animals."

The Society's Premium, value £3 3s., for members of affiliated Societies, to Mr. R. H. Cunningham for his paper on " Irrigation in India."

A Society's Premium, value £2 2s., to Mr. James Tonge for his paper on " Uses of the Hydraulic Mining Cartridge."

Mr. Shenton also expressed the thanks of the Society to the authors of papers for which Premiums had not been awarded, viz., Dr. Herbert Chatley and Messrs. T. J. Gueritte, E. Kilburn Scott, and Wm. T. Taylor.

Induction of the President.

Mr. Shenton then invested his successor in the Presidential Chair, Mr. Norman Scorgie, M.Inst.C.E., with the President's badge of office, and presented him with the certificate of his election as President.

Mr. Scorgie took the chair, and said : Gentlemen, the first duty I have to perform is a very pleasing one, and that is to ask you to accord to the retiring President your hearty thanks for his efforts and for the ability with which he has discharged the functions of his office during the past year. There is no one who has had the pleasure of working with Mr. Shenton who does not know how devoted he has been to the interests of the Society, both at the ordinary meetings and in connection with the Council meetings, and I am sure that words are unnecessary from me to ask you to accord with acclamation your best thanks to him for his services as President during the past year. I have to ask Mr. Twelvetrees, a Past President of the Civil and Mechanical Engineers' Society, to second the resolution.

Mr. W. Noble Twelvetrees : I need scarcely assure you that it gives me the greatest possible pleasure to second the resolution which has been so appropriately and so ably proposed by our President. Personally, I am afraid that I do not feel so well qualified as he is to be connected with this resolution, although I heartily agree with it. My reason is that, unfortunately, I have been prevented from being present at as many of the meetings of the Society as I should have liked to attend. However, I have had the pleasure of knowing Mr. Shenton for some time, and I know how thoroughly he takes up anything which it is his duty and his pleasure to perform. Mr. Norman Scorgie, our President, has already put the matter to you far better than I could hope to do, and, as he, with his greater knowledge, said that very few words were required, I think that you will agree with me that still fewer words are required from me. I have very great pleasure in supporting the resolution.

The vote of thanks was carried unanimously, and acknowledged by Mr. Shenton.

Mr. Norman Scorgie then delivered his

Presidential Address.

I APPRECIATE most fully the honour you have conferred upon me by electing me your President for the ensuing year, and feel it my duty to take the earliest opportunity of expressing my most heartfelt thanks to you, as I do now, for this mark of your esteem.

It will ever be my earnest endeavour to emulate the good example of those who have preceded me, by promoting the interests of the Society to the utmost of my ability ; and I know I may rely upon the cordial assistance of all the Past-Presidents, the Council, and the Members generally to enable me to make the ensuing year, notwithstanding the adverse conditions, one of pleasure and profit to all, individually as well as collectively.

This knowledge has prompted me to accept the office without that feeling of fear and trepidation which would otherwise prevail within me.

It has become almost a customary rule in this Society that the president on taking office should attempt something in the nature of a general survey of the branch of engineering with which he is connected,—its progress and its prospects. Noteworthy exceptions prove that we should have suffered if all past presidents had felt themselves bound by any such rule ; but on the whole it is probably a very sound custom for a society such as ours, whose members are drawn from all classes of the engineering profession, civil and mechanical. A general survey is more

likely to be of interest to the majority of members than a closer, more technical paper, when it is not concerned with their own work ; and the breadth of the society brings about in the ordinary course of things such a diversity of presidents that we are not likely to become wearied by repeated resumés of the same subject. It is for instance twelve years since a practising municipal engineer occupied this chair, and he was the first in the history of the society.

Moreover if the survey is confined to the author's own branch it is more likely to have value as well as interest. Of course the society has often been fortunate in having presidents able to handle broad issues in an illuminating form, but in my own case I am very conscious that a busy municipal practice in crowded North East London is not the ideal atmosphere in which one would prepare a presidential address of abstract contemplation.

In our time every branch of engineering has become noticeably more intensive, more complex, but municipal engineering has been peculiarly influenced by the aggregation of people in towns, the occupation of whole towns and even groups of towns in particular trades, the modern conditions of transport, and all the other problems that arise from the endless efforts of man to conform to a social environment which is constantly changing, and, of late, changing so rapidly that it seems to have been revolutionised within the five and thirty years since I commenced my career in public service.

In these changes municipal engineering has received less relief from specialization than other branches. Railways and great engineering firms all over the country are introducing more and more specialization, so that for economy of production and administration, brains are being classified and organised as much as labour. But the municipal engineer is denied this relief. Admittedly the larger undertakings, mostly classed as municipal trading, are placed in special hands. The Borough Engineer is no longer called upon to design a town hall in his spare moments, or to manage a tramway system as a hobby ; but this is a limitation on the amount of his work and not on its range. He must still be architect enough to add to the town hall or adapt an old one to new uses ; he may still have to instal the tramway system, and will certainly be called on for inspiration in any difficulties that arise in its working ; he may not have to manufacture gas or electricity, but he has to possess a knowledge of their manufacture and the actual cost of production, before he can persuade the gas or electrical engineer to sell them at a fair price for public lighting ; he must be something of a bacteriologist to deal with sewage ; and more than a little of a lawyer in order to pick holes in the opinions of eminent

counsel in matters of public health law; and, finally, in the present year, he must be an expert in designing shaded colour schemes for London, and in digging trenches to defeat German howitzers.

The reasons why municipal engineering has not been specialised are fairly obvious. (I am using this term throughout as a convenient one for civil engineering under local authorities although they may not be municipalities). To some extent it may be that a Council of voluntary laymen compares unfavourably with a board of paid directors in dealing with administrative eform. It has not the stimulus of trade competition to induce it to take the best advice and the most elaborate pains to effect conomies and improvements; and on the other hand it has to fear an electorate which, in some instances, is apt to assume that high salaries are necessarily wasteful, and that cheap labour is good labour. But if all this be admitted, it is not a sufficient reason, because the influence of lay control on engineering, whether by public authority or by private directors, is necessarily becoming less as the work of the engineer becomes more technical. The 18th century saw the end of the period when a well educated man might hope for a working knowledge of all professional lore in current use,—although, unfortunately, the 20th century still produces laymen who think they have that knowledge.

The real reason for the difference in this connection between municipal and other engineering seems to me to depend on the nature of the work itself, and the conditions of local government in this country. In commercial engineering a large output is clearly one of the conditions for success, and the impulse to specialize in one particular line can be encouraged, and it is encouraged by studying local resources to such an extent that whole districts are devoted to the manufacture of one particular article; which, as I have already suggested, only increases the difficulties of the unfortunate municipal engineer, who must know the process as thoroughly as the manufacturer himself, in order to make proper sanitary provision for waste products and other special conditions brought about by the trade. Where engineering firms still continue a wide range of output, or where they enter upon new work, such as the armament firms taking up motor car manufacture, the work is specialized, with separate factories, separately controlled. They may advertise that their motor cars are "built like a Dreadnought," but I venture to question whether the chief naval designer had much to do with them. In the motor car trade itself, as an example, the tendency is in the direction of specialization in one design, or at any rate, a very limited range of models, for each firm. We may deplore this from an uneasy feeling that it will have a paralysing effect on initiative; and we

may sincerely hope that it will never attain such dimensions in England as it has in America, so that very obvious errors of design cannot be altered because of the expense of altering machinery dealing with such enormous outputs as one complete motor car every forty seconds. But we must recognise that this tendency is winning on its merits, and endeavour to meet such evils as it brings in its train by striving to improve the status of the engineer so that the designer may have the controlling voice in the factory.

Similarly in railway engineering, specialization increases although the conditions are different. Railways cannot limit themselves to the carriage of one class of goods, or the design of one type of locomotive, but they can substitute and are rapidly substituting, delegation for decentralisation. The engineer for the A district and the engineer for the B district are giving place to engineers for this particular work and for that, each over the whole system ; such as one for the track only, another for signals and telegraphs, a third for bridges and tunnels.

But local government by small areas makes anything of this sort impossible in municipal engineering. The town council cannot specialise in house refuse, and refuse to scavenge or light the streets, and on the other hand it cannot afford, since its area is small, to pay adequate salaries to a number of separate experts. Therefore the municipal engineer is bound to be something of a jack-of-all trades (although not, I hope, master of none). He must know something of everything and everything of something, be an opportunist, doing his best with the material ready to his hand, hampered on every side by limitations and vested interests. His plant is largely classed as unproductive. His results are increased public convenience and reduced death rate. They are often very striking, but they are not directly measurable in pounds, shillings, and pence ; or rather payment is not made directly in those terms to his employers. If a railway engineer can satisfy his directors that a proposed widening will increase earnings or decrease working expenses by a sufficient amount, they will let him proceed, and if his estimate is sound the board will recoup their outlay and satisfy the shareholders. By elaborate traffic censuses the municipal engineer may prove that a certain road or bridge widening would repay its cost to the public at the very lowest estimate of the loss caused by the present congestion, but (in default of a toll) he cannot produce the money to the town council, or they to the ratepayers.

Public expenditure, both national and local, is constantly increasing, and one can see no sign of any check. (I am speaking of the normal conditions before the war.) Old-fashioned ideas

of economy have broken down. The public is in revolt against the belief that the spending of money is always an evil to be avoided if possible. There is grave danger that for want of guidance they may incline, indeed they have inclined, to the opposite fallacy that all spending of money as long as it is on public objects is a good thing to be encouraged as much as possible. Ignorant or interested opposition to all municipal enterprise was able to conceal from the public for many years the fact that the value or productiveness of work for the community at large cannot properly be measured in the only term known to private enterprise—a monetary dividend. Now that they have awakened to that truth, and the opposition of the company-promoting financier is discredited, it is naturally difficult to get them to distinguish between the financier and the economist, or to realise that municipal work is just as much subject to true economic principles as any other form of expenditure. I venture to suggest that every young engineer starting in municipal practice should consider a grounding in the science of economics an important part of his professional training, so that he may be able to advise his Council on the economic aspects of any proposal that comes before him, and they may pass on the information to their constituents. Whether it is a new open space, or a housing scheme for a slum area, a new system of scavenging, or a new tramway line, or anything involving expenditure within the province of the municipal engineer, it should be possible for him to arrive at the actual gain to the community in terms of money, after making proper deductions for benefits accruing to a particular class only or to persons outside the area of taxation, with a reasonable margin of error, varying according to the information at his disposal, and likely to become less and less if the estimate were properly made in all cases, and statistics accumulated. If his calculations are correct this return on the capital, good or poor as the case may be, is a perfectly definite thing, although the expenditure may be unproductive in the financial sense. Ten shillings a year saved in the doctor's bill for each household is as tangible as a ten shilling reduction in the rate demand note.

I am not posing as an advocate for or against municipal trading, but I am suggesting that the misleading division of municipal expenditure into productive and unproductive is one which the municipal engineer should combat, and in its place he should strive to set up an enlightened public opinion as to the real aims and productiveness of his work. It is public ignorance of the difference in the material results to be expected from it and other forms of engineering which condemns him on the one hand to the use of obsolete devices in the interests of so-called economy, and on the other hand to embark on unsound schemes

for the sake of an immediate profit or saving. It is not possible in the space at my command to elaborate this in detail, but a simple example from the case of a municipal tramway system may illustrate it. Suppose two extensions are proposed, one to an already overcrowded part of the town, the other to a healthy undeveloped part. The first could be worked at a profit from the start, the other not perhaps for some years, and yet if we take into account the decrease in overcrowding and the eventual increase in rateable value, the latter may be the better scheme. Or again, consider the current assumption that a tramway system in a town of less than 50,000 is bound to be unprofitable. Unless we have carefully considered the extent to which it is patronised, the saving of health in bad weather, the saving in cab fares to the well-to-do. and in time and shoe-leather to the poor, the possible extra employment and increase of population, and many other factors, we are not entitled to make that dogmatic assumption. I do not overlook the factors on the other side that ought to be considered also, particularly the possible unfair incidence of the rate, and the competing claims of the motor bus ; I am not trying to solve a problem, but merely to indicate some of the complications in the way of a borough engineer who is honestly striving to make his advice to his council a source of strength and not a string of platitudes.

I have said already that our work, extraordinarily interesting as it sometimes is in its variety, is not work in which one has either the leisure or the inclination for abstract speculation, and I am not going to depart from my own rule except to consider briefly whether the present wide scope of municipal engineering is likely to be a permanent condition.

In recent years it has probably been of some advantage to the profession as a whole that one branch of it should have remained exempt from the increase of specialization ; because specialization always produces a temporary decline in status. We are apt to value a thing by the price it will fetch, and a man by the salary or fees he can command, and if the work of an engineering post, formerly held by one man, is split up among several, it is clear that the individual salaries will be smaller and the status of the holders to some extent less than that of their predecessor. It is only a temporary depresssion for two reasons : first, if the change is a good one it will lead to such an increase of business that the separate appointments will eventually be worth more than the original one ; secondly, and more important, in the case of those firms and public authorities whose work is largely concerned with engineering the importance of engineering knowledge in high places is becoming more and more recognised, so that while the purely professional work of a chief engineer may be abolished by the division of

it among independent departmental engineers, yet the appointment of an engineer as chief executive officer is becoming usual. The title "Engineer and Manager," or "Engineer and Secretary" is now common. Even large railway companies have begun to follow foreign example and appoint an engineer as general manager; and under many public authorities (which it would be invidious to mention) the engineer enjoys that most satisfactory proof of status—a higher salary—although the clerk is by surviving custom or Act of Parliament the first official.

In any event I do not suggest that this service of unity in a period of temporary disunion, which municipal engineering has done to the profession as a whole, is a permanently valuable one, because I am not among those who think that the status of engineering is permanently at the mercy of anything except the merit of the engineer. One simple safeguard we should have, such as every profession has found necessary for its protection against charlatans, namely that no one who is not properly qualified should be allowed to call himself an engineer. Beyond that I think we could work out our own salvation without the aid of many shibboleths. It may be argued that those professions which by common consent enjoy the highest prestige, such as medicine and law, are protected by elaborate codes of etiquette and internal discipline; but it should be remembered that those codes are late products in professional history. Whatever we may think of their value, they are the devices of a professional class to preserve a position which it has already won on its merits and without their assistance. The lawyer class became influential in England as soon as the legal system developed, because of their superior knowledge of it, and their right of exclusive audience in the courts was the result and not the cause of their influence. And in medicine it is probable that nowadays the surgeon enjoys a slight professional and social precedence over the physician, yet the surgeon is a comparatively new comer to the medical profession, the common barber promoted. He owes his promotion solely to the merits and exactness of modern surgery. The moral of this on engineering status is important enough to be worth emphasising. It should encourage us to do everything in our power to set a high standard of professional service, and, as the retiring president pointed out in his address last year, of independent service. The value of the doctor's prescription over the patent medicine is partly its independence of trade interest. The barrister has maintained his right of audience when other monopolies have broken down, because his services, at his usual fees, are at the disposal of all; he may not refuse a brief or claim a special fee because he does not like a case or a client. These analogies should also save us

from depression when we do not see those results which we should like from the activities of this and other engineering societies within the limits of a few years. The village inn-keeper as surveyor of highways some years ago, or even the village cycle-repairer blossoming into the motor engineer of to-day, may seem a low ancestry, but that of the barber and apothecary was at least as low.

There are some grounds for suggesting that the exceptional breadth of municipal engineering may pass away and give place to specialization to some extent. The co-operation of local authorities for particular purposes has often been encouraged by Parliament. Possibly it is owing to their rather short-sighted reluctance to take advantage of it, that the tendency of recent legislation is to ignore the district and the small borough, and make the county and the county borough the only administrative units. There are, however, (excluding the main drainage system of London) 42 joint sewerage boards acting for about 110 local authorities, including such important towns as Birmingham and Brighton.

There are two or three parts of the country in which such population and wealth are gathered together within a limited area that the community could afford to pay for a very considerable amount of special service. One of them is London. It finds work for a large number of municipal engineers. In the Metropolitan boroughs, where their work is very similar to that of their colleagues in the provinces, and the county boroughs, boroughs, and urban districts of Greater London, where it is identical, there are about forty men holding chief appointments, in no way distinguished from one another or from those drawing similar salaries in other parts of the country. Yet their collective cost is greater than would seem necessary for London compared with provincial towns on a basis of population, size, rateable value, or even traffic. It is obvious that forty men of similar ability, paid similar salaries, but each a specialist in one class of work and in charge of that work over the whole of London would be very much more efficient in themselves at no increase of cost to the public. I am not advocating this as a desirable reform. Specialized efficiency is not popular at the moment because of its supposed identification with German methods ; and to say that they would be more efficient in themselves does not prove their ultimate value under popular control. The brain power delivered in the committee room is often heavily reduced by inertia and friction before it reaches the wheels. London suffers from an extraordinary lack of any sense of corporate unity, and, in the absence of that cementing force, it is most probable that local areas under the control of local

councils, areas small enough to be conscious of physical unity in default of anything better, are the best form of government.

Historically the development of London government might have been very different. The ancient city might have extended her boundaries slowly so as to embrace the whole, which would probably have brought about by this time some such system as I have suggested. Alternatively the outside districts might have been treated less like the cinderellas of local government, and might have adopted a system of federation with better prospects than the Metropolitan Board of Works started with. Federation is the only method of government which the wit of man has yet devised, able to reconcile local jealousies with a growing sense of unity. The gradual expansion of the City would have prevented these jealousies arising, but, failing that, it would seem as if federation were the only method by which Londoners could have been brought to believe in London. The creation of a directly elected County Council has unfortunately only produced 28 examples of the jealousies that commonly exist between any county council and the non-county boroughs within the county. Moreover it is an inexpansive system. Independent authorities outside a federal scheme will often in self-interest elect to come in, but it is impossible to imagine that the Boroughs outside the County of London will ever of their own free will come under the control of an external London County Council. Their opposition may postpone the whole question ten or even twenty years, but sooner or later London government will have to be dealt with again, and most probably the next time on federal lines. Federation itself, of course, would not necessarily produce a great amount of specialization in municipal engineering, but since it almost always leads to closer union it would probably be a step in that direction.

Municipal federation is also becoming a possibility in other parts of England; for example, in the Birmingham district and in the Manchester district; indeed in the latter it is almost an issue of current municipal politics.

But before these tentative influences arising from unity of local interests can affect the profession (that is, the branch of it with which I am dealing), it is likely that another influence, new within the last decade, and arising from a unity of interest all over the country in urban and rural areas alike, may have a profound effect upon us,—I mean the problem of the road. This includes not only the question of road construction and maintenance but the whole problem of transport, from town planning to traffic regulation.

The advice and complaints of the general public to the road surveyor are no more valuable than other outbursts by "the man in the street" on technical subjects which he does not

fully understand. Statements as to the bad condition of roads are often untrue or misleading. The testimony of foreign delegates to the Road Congress in 1913 was that English roads on the whole were distinctly superior to continental ones. This may be discounted to some extent as mere politeness to their hosts, but in my own experience, based on considerable road travelling in France and Belgium and in Germany and Austria, no one who has not seen the ordinary condition of the roads which form the suburban approaches to a continental manufacturing town has any right to call a road bad. And even when a stretch of English road has fallen into a deplorable condition it is often due to the parsimony or ignorance of the road authority and not to the incompetence of their surveyor.

But while urging all this, it would be idle to deny that for one reason or another road maintenance in this country is a duty which is very unevenly performed and a burden which is every unevenly distributed under present conditions. The departmental committee on Highways (1903) found the roads of England and Wales in the hands of some 1,900 local authorities pursuing widely divergent policies. The recommendations of the Committee, which would have introduced a modified nationalization by government grants administered through county road boards for the whole of a geographical county (including county boroughs within it), have remained a dead letter through the apathy of the Local Government Board. But with the growing importance of the roads, and their increasing cost, which is now about £15,000,000 a year and greater than that of any other country, it is inconceivable that any control can long be suffered to remain in the hands, for example, of rural district councils who, in some cases, appoint as their surveyors unqualified persons at salaries as low as £40 a year. Public opinion and recent Parliamentary action seem to be in favour of more centralised control.

The Royal Commission on London Traffic recommended a central traffic board for the whole of the London area, and a reform is none the less a reform because it is overdue. The reasons which led the Commissioners to this conclusion for London, namely the singleness of the object to be attained and the inability of any existing local authority to command confidence over the whole of Greater London, apply in a greater or less degree to many other large urban areas in the country.

The creation of the Road Board in 1910 is another conspicuous advance in the policy of centralization, although for the present limited to financial assistance and advisory propaganda. The policy of the Board in confining its attentions principally to county main roads may be unfair to the metropolis, to county boroughs, and to other boroughs and districts

in respect to their non-county roads, but a halting or inequitable beginning cannot alter the fact that the nationalization of the roads has begun. The statutory power of the Board to make and maintain roads of their own emphasises this.

Finally the government is committed to a policy of fostering co-ordination in regard to town planning schemes, and from fostering to compelling is a short step in twentieth century political opinion.

All these are reasons for thinking that a very profound change in the position of the municipal engineer may be near at hand. He began as a surveyor of highways, he may likely end as such. If the roads are taken from him the greater part of his daily engineering work will go with them. It is not really a question of taking some roads and leaving others. In urban areas the distinction between the county and non-county road has generally been rather a matter of financial juggling than substantial fact, and what substance there was has vanished with the coming of the motor. The speed of horse-drawn vehicles was so nearly alike and therefore the loss of time due to congestion so relatively small compared with the total journey, that there was little temptation for a driver to leave the main road for a worse paved, worse lighted side route ; but with motor traffic there is every inducement to avoid the relatively high loss of time due to congestion. The result is that the so-called side roads may have to bear a more wearing traffic than the main roads. Not only pleasure cars seek out such roads, but heavy commercial vehicles also ; indeed the profitable employment of motors for delivery work in particular depends on their ability to maintain a high average speed as a set-off against their great first cost. Even the motor omnibus is taking to the side roads. Those in control of omnibus policy (and there are none shrewder) seem to be satisfied that it is more profitable to encourage through long-distance traffic by speed of transit rather than to dally over casual passengers in the crowded thoroughfares.

The artificial restriction of traffic, whether generally or to particular roads, was discredited 150 years ago, and is not likely to be revived to any extent ; and anyone who has seen the condition of an average suburban side road of a few years ago after six months' motor bus traffic, will admit the folly of trusting such roads to less expert control than the others. (As a matter of technical fact there are no main roads in London.)

In rural areas the distinction between the county main roads and the district roads is not perhaps so obsolete, but it is in process of decay. If you will take the trouble to compare a map of county roads with a map of through routes prepared for motorists you will be surprised at the variations. Motor

traffic is through traffic in a way that even coaching traffic never was in turnpike days, because of its greater volume and fewer halts. The Roman roads, which are chiefly noticeable on a modern map for running a straight course and seeming to avoid all intermediate centres of population, have suddenly become the most important arteries of the country. In the county of Nottingham a portion of Roman road derelict for centuries has been reconstructed to form part of a through route avoiding Nottingham itself.

The existing distinction between main roads and others is most unfair and anomalous financially. From the decision of the county council as to classification there is no appeal, with the result that enlightened counties "main" all their important roads, whereas others shirk their responsibility, or trifle with it, as in a recent example where a county wished to prevent a borough amalgamating with an adjacent urban district to attain county borough size, and was alleged at a Local Government Board inquiry to have "mained" an extensive number of the urban district roads as a bribe to the district to oppose amalgamation, while the revenue for their maintenance came chiefly from the unfortunate borough.

If a new road engineer displaces the county and the district and the borough surveyor of to-day he will control not only the surface but anything underneath the road. Public opinion is becoming intolerant of the multitude of authorities with power to open up a road, and it is difficult to imagine that it would consent to a separation of the highway from the sewerage authority to any great extent.

If there is anything in this view that the engineering work of such officials as myself will shortly pass from the control of local authorities to that of the state or of road boards acting for much larger areas than the present authorities, it would seem to be an additional reason why I should devote the latter portion of this address to a review of the present position of municipal engineering, which I postulated at the beginning as the safest course for a president who is a municipal engineer.

It would hardly be an objection that Mr. Patten Barber gave us such a review 12 years ago, for presidential addresses, even the best of them, are ephemeral things, and, although I have been struck with the accuracy of many of his forecasts, it is clear that a great change has taken place since he was able to ascribe the need for better roads as impressed on road authorities by "the enormous increase in the use of the roads by cyclists rather than by horse vehicles." Even Mr. Silcock (who dealt with some of the greater problems rather than the everyday work of a municipal engineer) could say as late as 1909 that "whether or not the volume of motor traffic is likely to increase largely

in the future is open to doubt" and find reasons for thinking that it would not. But the doubt is settled when the motor cabs and omnibuses in London have doubled in the interval, and the increase of motor vehicles of all kinds in the country was 87,536 for the year 1913, or more than 25 per cent of the gross total at the end of the previous year.

For two reasons, however, I wish to avoid the task of a general outline. The first is that it would inevitably begin and end with the road. The road problem seems to have attained the all-engrossing position in municipal engineering that one pictures the battle of the gauges occupying in railway engineering in the forties. The available literature of recent date is truly formidable, but very accessible. I could contribute nothing personal to-night which I have not contributed to recent discussions here and elsewhere; and to summarise the mass of literature would be a valueless task (even if within my powers) inasmuch as we are in a transition stage in which we want evidence not conclusions. The cry is for a new Macadam; but Macadam spent 30 years in detailed investigation before he began to publish his conclusions. We may hope that the problem of the best road construction for the needs of the immediate future will be solved in less time, since hundreds are working on it, but hasty generalisations are the price we pay for limited individual experience. Unfortunately the English temperament as represented on our highway authorities is one of profound distrust of scientific investigation, which is classed as "tomfoolery." The surveyor is sometimes told to stick to old and tried methods even after they have been tried once too often and failed. In order to secure the laying of a piece of experimental roadway he must minimise the experimental nature of it and magnify his belief in its stability. This of course is another argument against the continued existence of the small road authority with a small revenue to whom an unfortunate experiment is not an incident on the road of progress but a disaster, perhaps a sixpenny rate.

But a more serious reason why I should break with precedent is to some extent to be found in a national situation which is without precedent in the lifetime of the Society or its members. A current review means always a considerable amount of prophecy (I have been led into some already), reasoning from the present to the future; and we are living in a time when such reasoning is futile. The direct influence of the war on all forms of engineering will be very great, and some of it is already apparent, for example the vital importance of standardization in all material likely to be needed for military purposes. But much greater than the direct effect is going to be the indirect ffect on our national temperament. It is one of the ironies of

the situation that a war against German militarism is educating us to the importance of the military aspect ; that in revolt against soulless German ideals of efficiency we are really developing our own ideal of national efficiency, of local and individual sacrifice to the common good, alien to the English character hitherto, which has placed the liberty of the subject higher than the general interest. It is due to this trait in the English character and to our freedom from foreign invasion that England is pre-eminently the home of local government. We have taken an institution to our hearts and endured any amount of incompetence, of corruption even, as long as it was local. In the future possibly the accent may be shifted and we shall insist on good government as the first condition of survival.

Since I believe, therefore, that a considerable change must take place in the conditions of municipal engineering before very long, and since it is impossible to predict now what the changes will be, I propose to do the next best thing and conclude this address with a summary, as condensed as possible, of those conditions in the past, that is the administrative system under which municipal engineering has developed to its present important position. It will save us from the temptation to rash prophecy if we appreciate how much it is a romance in recurring cycles, that with material progress there is not necessarily progress of ideas, merely history repeating itself. The municipalities of the 15th century were wonderfully efficient for the needs of the time, and staunch exponents of the first principle of good government—that along with the right goes the duty. Some of the records which have been edited (of the Borough of Leicester, for instance), exhibit the corporation shouldering their obligations with a very remarkable absence of quibble or evasion. Then by the end of the 18th century they were hopelessly decadent, and now they are once more a power in the land.

The highway system also has its history in cycles. The Roman roads must have been under the state, but mediæval England reverted to local control. Then the coming of the turnpike and the influence of Telford and Macadam seemed on the point of making them national again, when the rise of the railway put an end to it all and revived the despised parish system. To-day we seem once more on the eve of nationalization ; but if some extraordinary improvement in the safety and convenience of the aeroplane should suddenly relegate the Road Board and motor cars into the obsolete, it would be no more striking and unexpected than when the locomotive bankrupted the turnpike trusts and abolished the stage coach.

The early history of the road is obscure. A " highway " meant in mediæval days a right of passage and not a special surface. The obligation to maintain the way unimpeded was

probably on the adjacent landowners, but any improvements in construction were due not to the law but to the benevolence of pious founders or religious houses. A considerable decline in the amount of travelling seems to have coincided with the decay of manorial rights and monastic wealth, so that the roads fell on evil days; until an Act was passed in 1555 which for the first time put a statutory liability on the parish as a whole, and for 300 years that policy remained the basis of road maintenance. In that Act originates the Surveyor of Highways, chosen by the parish to serve gratuitously for a year. Highway rates were sometimes attempted from the 17th century onwards—Hackney had a 6d. rate in 1699—but until the end, the compulsory labour and teams which the surveyor was authorised to requisition remained the main resource of parochial road administration.

As a result of this combination of ignorant supervision and reluctant service the parochial system never got beyond "soft dirt roads, mended with weak and rotten sand and gravel." An extraordinary machine, the road plough, drawn by six or eight horses, was wont to open the roads in the spring "by ploughing them up, casting the furrows towards the centre, and then harrowing them down to a fairly level surface for the summer traffic." This was a condition of things that made wheeled traffic unknown in the remote parts of the country, and everywhere it was restricted by Parliament in the supposed interests of the road; but even the tyres of 19 inches statutory width did not prevent the cost of maintenance in some cases reaching as high as £121 a mile, a figure equalling about twice the rate for county main roads at the present time, when the difference in the value of money is taken into consideration.

The toll system, which originated in three toll gates being authorised on a portion of the North Road in 1663 to provide a fund for its repair, came to the rescue of English roads. The parish and the county justices were both passed over and Parliament established thousands of Turnpike Trusts from about 1706 onwards, which, although expressed to be temporary, all became permanent local authorities. The turnpike surveyor was supplemental to the parish surveyor, with whom his relations were very complicated, but he was commonly paid, and the trusts had a revenue (in all about £1,500,000 a year), so that road construction was considerably improved; at least the turnpikes had a convex surface and a substance of small pebbles and gravel, if no very good foundation. There were, of course, various forms of patent road put down by inventive surveyors. The Hackney road, we learn, was "laid wavy, or rising and falling . . . and men attend after rain to let the water out with their spades."

With the beginning of the 19th century the government and public opinion began to take the road question seriously. The necessity for military roads in the Highlands of Scotland, the Act of Union increasing communication with Ireland, and the establishment of the Post Office all contributed to this. The Holyhead road passed under the control of national commissioners with Telford as their engineer, and by 1830 three-quarters-of-a-million had been expended on it. Meanwhile Macadam was driving home his principles, not only as to road construction, which he could practise on the 600 odd miles he controlled as surveyor to 34 turnpike trusts, but of road administration, particularly the need for paid and trained surveyors and paid labour. Trusts were being consolidated on all sides, and the condition of the turnpike road was improving out of recognition. It would have seemed a very far-fetched prophecy in 1830 to say that England would ever again rely on the rejected parish system. Yet this is what actually happened owing to the introduction of railways and the resultant bankruptcy of the turnpike trusts. The authorities for which Telford and Macadam had laboured were doomed, but the principles of these men triumphed in the Highway Act of 1835 which enabled the parish to pay their surveyor and to levy a rate.

Although the Act did not apply originally to turnpike roads they gradually fell into the general system. The process was long drawn out,—the last toll was not levied in London until 1872, and in the country until 1895. (Of course private tolls which are not turnpike still exist). It is from the natural reluctance of the highway authorities to accept the burdens of the insolvent disturnpiked roads that the county main road originates. First came the Grant in Aid (1876); then a contribution of one-half the cost from the county (1878); and finally by the Local Government Act of 1888 the whole burden of disturnpiked roads, and any others which they might accept as "main" roads was put on the new county councils with additional aid from the government. This is an interesting example of the difficulty of understanding the administrative system under which municipal engineering works without a knowledge of its past. Now that the county council is the authority for main roads it seems a grievance (to which I have already alluded) that no one can force the council to treat an important highway as a main road. Historically explained, it is because the county was not the road authority, but the county funds were raided to meet the special case of the disturnpiked road, important or not.

Meanwhile a struggle was going on for half a century after the Highway Act of 1835 while the 15,000 separate parishes endeavoured to maintain their autonomy as road authorities

against growing public recognition of their inefficiency. For political reasons the Whig reformers who carried the Act of 1835 refused to recognise the Tory county justices as a possible highway unit. They did give parishes power to combine to elect a surveyor, but hardly any took advantage of it. The Highways Act of 1862, however, gave the county justices power to unite parishes compulsorily into Highway Districts under Highway Boards. Many parishes slipped out by adopting the Local Government Act, 1858, and turning themselves into Urban Sanitary Districts, until an amending Act of 1863 put a minimum population of 3,000 as a condition. We are now in the middle of the dovetailing and cross-working of highway law and sanitary law which make a municipal engineer's shelf of reference books more like a lawyer's than an engineer's. The urban sanitary authority had come in with the Public Health Act of 1848—the real starting point of modern municipal engineering—which had made the Local Board of Health (as it was then called) the highway authority for all roads in its district ; and by this time there were about 1,000 of them (including municipal boroughs). Elsewhere the rural parishes were being largely superseded by the Highway Boards.

The Royal Commission on Sanitation (1869) recommended the division of all England into sanitary areas, and accepted the poor law union of the county or the parish as the rural area. This was adopted in the great Public Health Act of 1875, and the Highway Act of 1878 provided that new Highway Districts should coincide with the Rural Sanitary Districts ; but (apart from old ones which did not) there were in 1891 still 6,501 parishes separately administering their own highways, so that the Local Government Act, 1894, which abolished both highway districts and highway parishes in favour of Rural Sanitary Districts, had a great work to do. On account of difficulties in adjusting areas the Act provided for postponement where necessary, and it was not until 1899 that the last surviving district and parish were each merged. Of the ancient responsibility of the parish that had come down to us from Tudor times nothing now remains excepting certain vetos and opportunities for complaint and the power to repair separate footpaths.

The history has not been simple, but the general result is so much an improvement on anything that has gone before that it seems almost ungracious to mar the outline of it by mentioning the anomalies and exceptions which still remain to the broad system of the council of a county or county borough as the authority for main roads, and the sanitary authority the road authority for all others.

Of anomalies we have the power of the county council to hand over main roads, and the right of certain urban districts

to demand that they should be handed over (already mentioned), also the case of a rural district council which has succeeded to a highway board, for its powers are slightly larger than if it had succeeded to a parish. When it has succeeded partly to one and partly to the other you may pity the local surveyor for the legal tangle in which he is involved.

Of exceptions we have first the Isle of Wight. By local Acts the urban districts were the highway authorities and in rural districts the Isle of Wight Highway Commissioners. The creation of a county council for the island did not abolish the Commission, but the county council had to make a grant to it, and it has now been held that the Act of 1894 abolished the Commission by implication, with the curious result that the rural districts of the island are in the happy financial position of having all their roads main roads.

South Wales is now assimilated except as to certain powers, but for many years it was an interesting exception, for the turnpike trusts were dissolved much earlier than in England, and the roads were turned over to County Road Boards under government control and with a government engineer.

The Scilly Isles have their own Provisional Order; and finally the metropolis is an exception to the whole system, ever since the Highway Act, 1835, left it under Michael Angelo Taylor's Act of 1817; and it has developed separately with its own highway and sanitary law. That we have no main roads is perhaps our only claim to simplicity over provincial administration, and certainly no provincial engineer who takes the trouble to find out the number of statutes affecting municipal work in London would envy us.

In this outline the municipal borough has been mentioned only incidentally as the urban sanitary authority under the Public Health Acts; yet it is clear that in all those branches of municipal engineering which are most important nowadays the borough supplies the greatest examples. The reason for the small part it has played in the earlier history of municipal engineering (in the wide sense in which I am using the term) is bound up in our forefather's conception of what a borough was, and their distinctly dirty manner of living. Just as a highway was not a piece of land but a right of way, so a borough to the mediæval mind meant not so much the place as the privilege; chiefly the privilege of exemption from the jurisdiction of the lord of the manor or the sheriff of the county. It was itself a bundle of jurisdictions often over different and very indefinite areas, and one of its most important privileges—the franchise—was personal and had no territorial limit.

Although in the 15th and 16th centuries the best of the corporations were faithfully fulfilling their corporate obligations

in such things as provision of work for the unemployed, yet it is not to be expected in spite of some rather well-sounding officials we meet with in the records—Street Keepers, Street Wardens, Sweepers of Streets, and (best of all) in Rochester "Scavenger to gather the money" with humbler subordinates to look after the dirt—in a time when highways were, as we have seen, of small account, that corporations should be much concerned to improve them. For the rest, our ancestors were not morbidly anxious about drains, and it was not until after the lesson of the cholera epidemic of 1847 that the general public health laws begin.

Yet populous and enlightened towns must have wanted to cleanse and light, to drain and improve their streets long before 1848. They did, and from about 1750 onwards there is a continuous stream of special Acts of Parliament to enable particular towns to cope with their needs.

In a few cases the powers were conferred on the corporation, or at any rate on commissioners controlled by the corporation. Liverpool is a striking example of a corporation having a very broad idea of its proper sphere of action in pre-reform days. It was continually securing local Acts, and was the first provincial corporation to get one for lighting, cleansing, and watching its streets. It constructed "the first docks ever built in England," and by 1825 it had spent two millions sterling on them. It spent also large sums on street widenings, free schools, and public baths, and it even built and endowed churches. Most extraordinary of all (although outside my subject) it maintained a London office, and it lent money to its citizens.

In most cases however, the new powers were being granted at a time when the common councils were declining in prestige, and Parliament preferred to confer them on new statutory bodies. These *ad hoc* authorities—Commissioners of Sewers, Paving, Streets, Police, for example—with their varying constitutions and powers, but all of them doing work which the corporation ought to have been doing, are the principal feature of municipal history in the hundred years before the reform of the corporations. There were indeed Commissioners of Sewers as far back as the fifteen hundreds, but the name misleads us if we suppose that sanitary legislation has had so long a history. "Until the 18th century a sewer was a ditch or cutting containing nothing worse than fen water," so that these early commissions were concerned with the drainage of marsh land, not of inhabited areas.

Probably the multitude of commissions was unnecessary, and the excessive distrust of corporations a mistake which itself bred corruption. "The watching, paving, lighting of the town, these m t ters were no affair of the corporation . . . . .

morally the town loses its personality for it loses its sense of duty," says the greatest of the borough historians. Many corporations struggling to do their duty met with violent opposition from the townspeople on political grounds. Bristol had the power to levy a rate for paving and lighting after 1748, but the inhabitants were not willing to pay any adequate amount to the corporation as then constituted, so that it had to surrender many of its powers, and by the date of the Municipal Corporations Act there were eight tax levying authorities in the city.

The records which most corporations possess from a very early date (and which some public-spirited ones are editing), are not only interesting but often important in modern practice. Since the municipal corporations were reformed the commissions have been dissolved and their powers transferred to the town council, but the majority of the local Acts, whether obtained by the old corporations or by commissioners, are still in force. They are further examples of the legal complexity which attends the work of a municipal engineer. To all the modern tastes and abilities which (as I have tried to convince you) are the qualifications for an ideal borough engineer, it looks as though we should add one other to complete his halo,—he must be something of an antiquary.

Mr. W. B. Esson : Gentlemen, it falls to me to perform a duty which is, indeed, a great pleasure. We have heard a most excellent address from the President, full of interest and of instruction, and as I followed his flowing periods most attentively I could not help thinking that he was, indeed, a very fortunate President, inasmuch as, in dealing with a subject which he has made his own, and in which he has attained pre-eminence, he was able to interest everyone of his listeners. As long as we are on the surface of the earth, and until we are ready to be put under its surface, we must necessarily all be interested in the great problems of municipal engineering—gas and water supply, sewage disposal, the making of roads and what not, and in the address which we have heard to-night we have one which has covered an immense amount of ground. I could go on praising at considerable length, but I am sure that you all feel as I do, and anything further I could say would consequently be superfluous. I will therefore at once ask the meeting to render their best thanks to the President, Mr. Scorgie, for his very able address.

Mr. Percy Griffith : Gentlemen, I have had allotted to me the pleasant and honourable task of seconding this vote. This is doubtless unnecessary, because all who have heard this address have listened to it with much interest and are as fully aware as I am of its intrinsic merits. The subject of this address is, at any rate, not on a " hackneyed " one, but is one of very vital impor-

tance to us, and the address has given us all much food for thought. I will not attempt to elaborate all the thoughts which it has suggested to me, but one is, I think, worth mentioning under the circumstances in which this nation finds itself. In this address you have learned that the history of municipal engineering in this country is practically identical with that of every other aspect of our national or communal life. It has been developed in a peculiarly English manner; that is to say, on no definite system, in accordance with no definite theory, but merely on the elementary system of "trial and error," with plenty of errors, each corrected when it became too serious to be borne. It is worth considering whether that system has any merits whatever to justify it, and I am bound to say that I cannot help being convinced that, with all our national defects, there must be something in us which compensates for these defects and overcomes the difficulties they entail, because we are still a nation worthy of respect, and by no means the least successful in regard to municipal matters. As the President has mentioned the war, which is now absorbing all our attention (including that of the municipal engineers amongst us), may I quote it as another example of our being taken unawares and almost totally unprepared, having had no experience of war under modern conditions, and being traditionally scornful of theory. I ask whether or not we are rising to the occasion, and I do not hesitate to answer yes. I think that that is the conclusion which we may fairly draw from the President's most fascinating address, and that we may flatter ourselves as a profession and a nation that while our methods may be weird, our results are generally fairly satisfactory. I say this rather with the idea of concentrating our congratulations upon our President for having brought before us a lesson which we appreciate, a lesson which, I hope, will be useful to us in the future, and enable us, perhaps, to learn how to do things before they are required rather than afterwards.

I am sure, gentlemen, that you will all unite with me in the vote of thanks which will now be submitted to you.

The motion was put to the meeting by Mr. Esson and carried unanimously.

The **President**: Gentlemen, if the few words which I have had the opportunity of putting together have met with your approbation I can assure you that it has more than recompensed me for my trouble in writing them, and the least that I could do in return for the compliment which the members have given me by placing me in the chair is to endeavour, as far as lies within my power, to give you the few notes on this most interesting subject, and I am extremely pleased to see some of my colleagues in the municipal engineering profession present to-night. I thank you very heartily for the vote of thanks which you have given me.

THE SOCIETY OF ENGINEERS (INCORPORATED).

BALANCE SHEET, 31st December, 1914.

Year ended 31st. Dec., 1913. £ s. d.	Liabilities.	£ s. d.	£ s. d.
168 14 9	*Sundry Creditors*		152 16 2
24 3 6	*Subscriptions in advance* ...		26 4 10
	Life Membership Account—		
	As per last Balance Sheet ...	84 17 7	
	Less Transferred to Income on account of Life Subscriptions expired	14 7 1	
84 17 7			70 10 6
	Society's Premium Account—		
	As per last Balance Sheet ...	24 5 5	
	Add President's Donation ...	5 5 0	
		29 10 5	
	Deduct Cost of Premiums ...	7 7 0	
24 5 5			22 3 5
	Clarke Premium Account—		
	As per last Balance Sheet ...	9 18 3	
	Deduct Cost of Premiums ...	4 17 7	
9 18 3			5 0 8
	Status Prize Account—		
8 8 0	As per last Balance Sheet ...		8 8 0
	Benevolent Fund Account—		
59 5 6	As per last Balance Sheet ...	59 5 6	
	Add Interest at 4%	2 7 5	
			61 12 11
	Accumulated Fund being excess of assets over liabilities—		
	As per last Balance Sheet ...	776 19 8	
	Deduct Excess of Expenditure over Income for the year ...	16 7 6	
776 19 8			760 12 2

Year ended 31st Dec. 1913. £ s. d.	Assets.	£ s. d.	£ s. d.
	Cash—		
217 7 2	At Bank Current Account ...	121 15 4	
100 0 0	,, Deposit Account ...	150 0 0	
4 2 1	In hands of Secretary ...	15 15 7	
			287 10 11
	Sundry Debtors—		
10 11 0	Subscriptions and Admission Fee in arrear and received at the date of Auditors' Certificate	16 5 6	
12 6 0	Advertisements in Journal ...	11 19 6	
	N.E. Rly. for July, 1914, Div.	2 12 0	
			30 17 0
	Investments—		
	£606 L. & N.W. Rly. 3% Deb. Stock at 86½, as per last Balance Sheet	524 19 0	
	£300 India 3½ % Stock at cost as per last Balance Sheet ...	278 13 6	
		803 12 6	
	Less Reserve for Depreciation ...	80 0 0	
723 12 6	(The market value of these securities at 31st December, 1913, was £721 12s. 5d.)		723 12 6
	Office Furniture—		
	As per last Balance-Sheet ...	31 8 6	
	Less Depreciation at 10% ...	3 2 10	
31 8 6			28 5 8

Previous year			
	Bessemer Prize Account—		
	As per last Balance Sheet ...	160 7 6	
	Add Income from N.E. Rly. Deb. Stock...	5 4 3	
		165 11 9	
	Deduct Cost of Premium ...	5 5 0	
160 7 6			160 6 9
	Nursey Prize Account—		
	As per last Balance Sheet ...	46 10 5	
	Add Income from Hammersmith and City Railway ...	1 14 2	
46 10 5			48 4 7
	Bernays Prize Account—		
	As per last Balance Sheet ...	26 7 8	
26 7 8	*Add* Income from N. and S.W. Junction Railway	0 17 5	
			27 5 1
£1,389 18 3			£1,343 5 1

Previous year			
	Library—		
	As per last Balance Sheet ...	36 4 0	
36 4 0	*Less* Depreciation at 10% ...	3 12 5	
			32 11 7
	Stocks on hand—		
	Transactions and JOURNALS ...	15 12 5	
	Law Lectures	1 2 0	
30 14 0			16 14 5
	Bessemer Prize Fund—		
154 9 6	£185 N.E. Rly. 3% Deb. Stock as per last Balance Sheet ...		154 9 6
	(Market value 31st December, 1913, £136 18s.)		
	Nursey Prize Fund—		
46 7 3	£33 Hammersmith and City Rly. Con. Ord. Stock, as per last Balance Sheet		46 7 3
	(Market value 31st December, 1913, £42 18s.)		
	Bernays Prize Fund—		
22 16 3	£13 N. & S.W. Junction Rly. Stock, as per last Balance Sheet		22 16 3
	(Market value 31st December, 1913, £22 2s.)		
£1,389 18 3			£1,343 5 1

THE SOCIETY OF ENGINEERS (INCORPORATED).

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31ST DECEMBER, 1914.

Year ended 31st Dec., 1913. £ s. d.	EXPENDITURE.	£ s. d.	£ s. d
	To Printing Transactions ...	188 3 6	
	Less Sales and Advertisements	37 17 6	
89 12 0			150 6 0
	,, *Administration Expenses*—		
300 0 0	Salary of Secretary	300 0 0	
85 0 0	Rent of Offices	83 11 6	
17 19 0	Fuel, Lighting, and Office Cleaning	15 16 0	
	Re-decorating Offices, Polishing Book-cases, etc. ...	22 12 9	
77 0 4	Postages, Telegrams, Carriage, and General Expenses ...	90 0 1	
59 18 0	Stationery & General Printing	62 2 11	
10 10 0	Audit Fee	10 10 0	
			584 13 3
	,, *Meeting Expenses*—		
19 19 0	Hire of Rooms	19 19 0	
18 7 6	Reporting Meetings ...	15 15 0	
5 15 7	Refreshments for Members at Ordinary Meetings ...	6 6 7	
			42 0 7
	,, *Employment Bureau*—		
	County Council Fee... ...	1 1 0	
0 16 2	*Less* Deposits forfeited ...	0 15 0	
			0 6 0

Year ended 31st. Dec., 1913. £ s. d.	INCOME.	£ s. d.	£ s. d.
686 1 7	By Subscriptions (Excluding all arrears not realized at the date of the Auditor's Certificate)		740 5 4
22 11 6	,, Admission Fees		34 13 0
2 13 0	,, Interest on Deposit		3 11 1
	Interest on Investments—		
	London and North Western Rly., 3 per cent. Deb. Stock	17 1 11	
27 0 0	India $3\frac{1}{2}$ per cent. Stock ...	9 17 0	
			26 18 11
1 4 8	,, Law Lectures Balance ...		1 0 0
—	,, Examinations Account ...		1 1 6
—	,, Balance, being Excess of Expenditure over Income for the year		16 7 6

22 7 9	,, Smoking Concert Balance ...	29 17 4			
7 15 11	,, Law Charges	7 11 6			
3 9 10	,, Depreciation of Office Furniture	3 2 10			
9 1 0	,, Depreciation of Library ...	3 12 5			
2 5 7	,, Interest on Benevolent Fund	2 7 5			
9 13 1	,, Balance, being excess of Income over Expenditure				
£739 10 9		£823 17 4	£739 10 9		£823 17 4

We have examined the above Balance Sheet and Income and Expenditure Account, and have obtained all the information and explanations we have required. In our opinion the Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of the Society's affairs, according to the best of our information and the explanations given us, and as shown by the books of the Society.

3, Raymond Buildings,
Gray's Inn, London, W.C.
8th February, 1915.

(*Signed*) BEGBIE, ROBINSON & COX,
Chartered Accountants.

1*st March*, 1915.

NORMAN SCORGIE, M. INST. C. E., PRESIDENT,

IN THE CHAIR.

RUNNING COSTS OF MOTOR VEHICLES.

By LIEUT. ROBERT W. A. BREWER, A.M.Inst.C.E., M.I.Mech.E., M.S.A.E.

[FELLOW.]

THE automobile engineer has as a primary duty, to effect the transportation of goods or persons from place to place in the minimum of time and at a minimum cost. As regards economy of time, the development of the high-speed motor car has shown that it is capable of competing with any known method of transit except the aeroplane. The second consideration, that of cost, is perhaps of even more importance, as transport on a large scale is a great commercial factor at the present time. This matter has received the attention of traffic experts during the past few years, and it would, therefore, appear presumptive to dilate upon the subject from the commercial point of view, but it will be profitable to discuss the main features which control the working costs, both of the pleasure car and the commercial motor.

Although the automobile has been developed to such a state of reliability that it plays a most vital part in the affairs of the world, there are wide practical divergencies, even now, between various types and various machines when their individual performance is closely examined. These differences of design and performance are manifest principally under certain heads, which may be set out as follows :—

1. Fuel cost and consumption.
2. Lubrication systems and consumption of oil.
3. Wear and maintenance.
4. Tyres.

The question of depreciation may be left out, as that generally can be considered under the third heading. All of these items can be directly measured, some of them from week to week, from the cost sheets, and others at longer intervals, when extensive renewals must be made. The object of this paper is to put on record certain known means by which some of these costs can be reduced, first investigating their causes and seeing how they can be influenced by the skill of the engineer.

The Sources of Cost.—The fuel cost is governed by a large number of circumstances apart from the particular locality in which the vehicle is operating. Naturally local conditions affect working costs to a great extent. The contour of the country,

frequency of stops, and the average speed of the vehicle are matters generally outside the control of the engineer, and we will therefore pass over them.

They do, however, affect the general scheme in determining the power which must be developed by the engine in order to surmount natural obstacles and to produce such an acceleration of the vehicle as will enable a good average speed to be maintained.

For many purposes, however, in the case of pleasure vehicles, we cannot put it down as an axiom that the engine which is *capable* of producing the greatest power, is proportionately a greater fuel consumer per mile of road travelled than a less powerful engine of similar general form There are so many other considerations which come into play that it is impossible to generalise on the relation between engine size and load factor on the one hand and fuel consumption on the other. Everybody is quite familiar with the fact that fuel consumption expressed in miles per gallon does not, within wide limits, vary between, say, a car weighing 1·5 tons unloaded with an engine of 100 mm. bore and a car weighing 1 ton unloaded with an 80 mm. bore engine.

There is a generally accepted figure of, say, 25 miles per gallon under ordinary working conditions, with petrol as fuel, which should be attained by all such vehicles. The fact is that, within limits, the power required from the engine to propel such a vehicle in an ordinary day's run would average 9 to 10 H.P. to be given at the road wheels.

Now a rather curious fact comes to notice. It might be expected that under given road conditions the small engine would be working at a higher volumetric efficiency, and would give manifestly greater economy than the larger engine working under presumably lower volumetric efficiency. In actual practice, however, this is not borne out, the reason being as follows :— The small engine operates with a reasonable amount of throttle opening, but in spite of this fact, its smallness of size precludes it obtaining a high rotational speed when top gear is in operation until such a time as its rate of increase of power is notably greater than the rate of increase of car resistance.

If these two factors are fairly equally matched, acceleration is small and an appreciable time elapses before a high car speed is reached. In this country, however, one cannot retain the throttle wide open for lengthy periods on account of road conditions. The volumetric efficiency of the motor will therefore not be unduly low. Were it possible to hold the throttle wide open, in course of time the car would attain speed and the power production of the motor increase proportionately or nearly so.

The big bore engine, however, is held in check during the greater part of its working period by reason of the small throttle

opening permissible, and with modern carburetting appliances it does not appear that its economy in working is much affected thereby. This may, in a measure, be really due to the fact that any losses incurred on the level are compensated for on gradients, when the motor can be kept running at a comparatively slow speed, the top gear being used, whilst its smaller brother is revolving quickly and operating through a lower gear ratio.

From theoretical reasoning the large engine working throttled down, *i.e.*, with reduced compression* should show a high fuel consumption, and on the test bench, of course, this is so, and we may take a round figure of 25% increase in consumption per B.H.P. per hour developed as representing the difference of fuel efficiency under the two conditions named.

Were it possible to continue for any lengthy period upon the road under the said conditions, no doubt an appreciable difference in fuel consumption would be shown. On the other hand let us consider for a moment how a great many fuel consumption road tests are made, as regards throttle opening. With the exception of those tests made by works testers upon a strange carburettor, the results which find their way into the Press are almost always obtained under a low load factor.

This may be due to several reasons such as a desire to keep the wind resistance down, so that the actual power required to be developed by the engine is comparatively small. Under such conditions the time element is considerable and the period occupied in covering a mile greater.

This is counteracted, however, by the fact that at a low speed the power developed by the engine is lower, and mileage per gallon tests usually take no count of the power developed, in other words the fuel per B.H.P. hour—and seldom of the fuel per ton mile.

The power is, however, an all important factor in making comparisons and the careful use of the accelerometer *in all such tests* is the only method of obtaining data of any real value.

The power developed by the engine as a mean value can only be gauged accurately by a recording instrument, but for comparative work, two different cars will afford the observer useful data. Several tests made by the author in this manner have proved very instructive in showing that, with careful driving, ordinary pleasure cars, in good condition, give very similar fuel consumption results though they may differ widely in general form and weight. The Author here ventures to express an opinion that the fuel consumption of an ordinary car reckoned in this manner is far from what should be obtained.

To proceed further with the investigation, let us follow the fuel

* The compression *ratio* is not reduced.

from the tank. Much has been said and written on the first process through which a liquid fuel must pass before it becomes a suitable agent to perform work in the cylinders of an internal combustion engine.

In no engine is fuel burnt in its liquid state, the motor with which we are most familiar being a gas engine requiring as its motive power a gas, homogeneous throughout its mass and uniform in quality from one period to another.

This latter observation is open to modification, however, from theoretical reasons, as it is a fact that a high compression can deal with a weak mixture economically. We know for a fact that when a large bore motor runs for considerable periods, say along a level road, at a low load factor, economy results from weakening the mixture and increasing the throttle opening.

Dr. Watson has graphically represented to the Institution of Automobile Engineers the fact that mixture strength can undergo a considerable variation without appreciably affecting the power produced at full throttle opening. By a careful manipulation, therefore, the critical point of the mixture strength and power curve can be avoided whilst economy of working of no mean order will result, when the maximum thermal efficiency can be reached, and the power remain unaffected. This fact will be considered later, but is mentioned to indicate the reason why the fuel efficiency of a large engine can become comparable with that of a smaller one under the conditions under consideration.

The Efficiency of the engine.—An internal combustion engine is termed efficient or otherwise, in a somewhat loose manner by the general public. By an engineer, however, the term "efficiency" may be applied in one of several meanings, *e.g.* :—

1. Mechanical.
2. Thermal.
3. Volumetric (swept by piston).
4. Specific Volumetric (H.P. per litre).

The mechanical efficiency is the most commonly considered in engineering practice being a survival of steam engine methods. In automobile work it is the least often referred to by reason of the fact that brake tests are the means usually employed for measuring the power output of an engine rather than indicated horse power. Probably this is one reason why the mechanical efficiency of the modern internal combustion engine is left to look after itself, rather than to become a scientific study.

As a concrete example, those who can quote a reasonably exact figure for the mechanical efficiency of a modern valve engine and a Knight engine are probably a small minority, yet working costs are much affected by this value as attained in practice.

Again, there is an absence of data with regard to such items as piston friction, either as a direct measurement or as a comparison between various types, such as cast-iron and steel, or parallel and waisted. The relative merits, too, of forced and splash lubrication for crankshafts are still a debatable point, although it is generally agreed that for heavily and continuously loaded shaft bearings, directly forced oil feed is the only system which will stand up.

The proper application of lubricant to bearing surfaces is a subject which has been well considered by mechanical engineers since the earliest days of the science, but many of the theories of ordinary mechanical practice have been entirely broken down by the advent of the automobile. The lubrication question is one requiring much careful thought and experiment by members of our profession, by reason of the fact that faulty lubrication is at the root of the majority of failures under really heavy loading. It is only necessary to recall failures in some of the more prominent races, to acknowledge the truth of this statement, yet advance in methods of lubrication has been very slow.

Racing conditions are complied with by trial and error, a laborious and expensive method, and in some quarters a departure from known and common practice will not be considered by reason of a lack of appreciation or understanding of the underlying principles. Yet there are, undoubtedly, certain principles which apply in the lubrication of a high speed crankshaft, which are peculiar to that part, and which must be considered accordingly.

In one case in which the Author was engaged, a very obvious fault in the lubrication of this detail was evident and was remedied by suitable treatment, the exact details of which were not disclosed until later. The results aimed at were attained satisfactorily, and there was no evidence of metallic contact having taken place between the lubricated surfaces after much hard running. When, however, the details of the alterations were made known to the makers, they were condemned as being unsuitable. The only reason for such an action could be that a departure was made from their own customary practice, combined with an ignorance of what was actually taking place under the new conditions. Such instances can be multiplied in other directions and a fuller knowledge must be gained before a great step can be taken in the reduction of engine friction.

Piston friction has already been referred to and even now there are no general data as to the effect of various modifications which have been made to reduce this. Apart altogether from the material and form of the piston, there is a great divergence of opinion upon the ring question. Not only is the number of

rings still an unsettled matter, but their disposition and shape also call for attention.

The Author's opinion tends to the belief that for touring car work a piston touching the cylinder throughout the greater part of its length, fitted with two rings at the upper end, should meet the case. By "touching the cylinder" a parallel clearance is inferred as distinct from a waisted piston.

In such a design, the various machining clearances are of great importance, particularly in view of the distortion, both of the cylinder and the piston shortly after they have been put to work. The Author has found this distortion to be very great in several different makes of engines, and the manufacturers themselves have scarcely credited the movement of metal which has been pointed out. Such practical considerations have an important effect upon the results obtained on test and show the necessity, when the best results are desired, for some heat treatment or rest between the operation of the first rough boring cut and the final grinding. The reason for this is two-fold, the expansion of metal and partial distortion at high temperature, and the presence of the oil film.

The Author has run satisfactorily pistons of 70 mm. diameter with a skirt clearance of six thousandths of an inch cold, without any sign of knock, and has obtained most satisfactory results as regards reduction of piston friction with this clearance. Insufficient piston clearance is responsible for a great deal of the loss of efficiency at high speeds which exists in many motor car engines and this is undoubtedly as great a source of loss as insufficient valve diameter.

Clearance of metal between the rings is a matter of some difficulty to define and depends upon piston thickness and design, but there is no necessity for any attempt at closeness of fit here. Importance must, however, be attached to expansion allowance for the rings and this should be from six thousandths to fifteen thousandths of an inch according to the perimeter of the ring.

Piston friction being so important an item in the total of engine friction, the question of piston *fit* is one requiring attention both by reason of the thinness of the metal and the available space for the lubricant. The former factor depends upon the degree of weight cutting which is to be attained and the latter is governed by the rate of linear piston speed to be maintained for continuous periods of working. Apart from manufacturing tolerances a convenient rule is adopted in some quarters of one thousandth of an inch of clearance in the diameter across the piston skirt per inch of piston diameter.

A proposal has been made in America to allow 2 thousandths to $2\frac{1}{2}$ thousandths per inch diameter of piston above two inches with a maximum allowance of 4 thousandths for a 2-inch piston

and 4·8 thousandths for a 3-inch piston. At this latter rating a piston of $3\frac{1}{2}$ inches diameter would have a clearance of 5 thousandths of an inch, which would be quite permissible in a high speed motor. It must not be forgotten that clearances in the state of cold metal do not represent working conditions, and although it may be supposed that piston knock might occur by reason of this apparent looseness of fit in the cold state, no actual knock would exist under working conditions.

With further regard to the piston itself much can be said, but when lightness of construction is desired the waisted piston has many features worthy of recognition. Apart from racing practice, and looking at the piston as a mechanical appliance whose function is to transmit the energy produced by the expansion of a gas into a linear movement, the piston has two main features ; first it must be sufficiently strong to resist all tendency for its head to collapse, and secondly, it must act as a thrust slipper, having a minimum of friction upon the cylinder walls.

The first consideration does not have much bearing upon the subject of this paper, but undoubtedly the second is of some importance. It is the Author's opinion that much unnecessary friction is entailed by reason of pistons fitting too closely at points where there is really no object in maintaining any contact at all. Therefore the waisted piston facilitates construction and tool work by requiring only a comparatively small area to be machined to a degree of great accuracy. Further the question of distortion is more easily dealt with by reason of the smaller contact areas. Time will not permit of a further digression upon this most important subject, but any definite data upon the question of the relative friction of pistons of different materials would be welcome.

Valve mechanism.—With the exception of the most elementary forms of two stroke cycle motors, all the modern internal combustion engines demand expenditure of work for the purpose of valve operation. It is difficult to state exactly how much of the total power developed is absorbed in this function ; probably only a small proportion, but it all counts. The only portion worth considering is that necessary to start the exhaust valves from their seats, a momentary effort. The actual mechanical efficiencies of valve and sleeve motors are no doubt approximately the same, in so far as valve operation is concerned, and in view of Dr. Riedler's experiments we may take it that there is little room for improvement in this respect.

Transmission losses.—Whilst considering frictional losses we will briefly pass from the engine to the transmission gear, and it is here in the majority of cases that the greatest scope lies for elimination of frictional loss. Modern methods of chassis construction tend towards the two unit system, where cheapness

of erection is concerned. Undoubtedly this is good practice, by reason of the fact that lining up need not be so carefully carried out.

The introduction of leather and fibre disc couplings has somewhat modified the problem, however, as such couplings are quiet in running, require no lubrication, and have a very low frictional loss. The interposition of such a coupling at each end of the gearbox, reduces frictional tendencies due to displacement of any transmission unit, though a two unit scheme attains the same end in a more mechanical way. Whether the double unit should be at the engine or axle end, or in the later case whether it should be at the front or rear end of the propeller shaft, has scarcely yet been definitely decided. Good arguments can be raised in favour of both methods, though we find that one great exponent of the two speed axle in 1914 has discarded this practice in the current year's model.

It is the author's opinion that rear axle weight is much too great, and that frictional losses could be reduced in a lighter design. Not only this, but a great unsprung weight imposes other losses of power when running on rough roads, so great that they are well worthy of careful attention.

The right angled drive is a subject upon which valuable data is already available. We will, therefore, omit this detail from discussion at the present time.

Gas friction.—So far we have dealt only with the frictional loss of lubricated surfaces, but there is another most important feature which controls engine efficiency and consequently working costs. It may not be apparent at first sight how gas friction plays an important part, as the actual friction of a gas passing through a pipe or port is comparatively small. Where the loss occurs is not the actual friction of the gas, in so far as absorption of power in driving the gas along the passage is concerned, but in the reduction of the volumetric efficiency of the particular engine.

Supposing we have for example an engine of certain linear dimensions producing a definite horse power at the brake at 1,000 revolutions per minute. The frictional loss due to lubricated surfaces is then a certain measurable quantity. At double the rate of revolution the frictional loss will be, say, twice as great, and in order to maintain the mechanical efficiency of the motor the power output should increase at the same rate as the frictional loss increases. If, however, the power output is restrained by a reduction of volumetric efficiency, the mechanical efficiency of the motor drops.

Now volumetric efficiency is a function of gas friction and if the latter is abnormally high we can quite conceive an engine with a very small brake horse power output at high speeds.

It is only necessary to refer to tables and curves which have appeared in the proceedings of the Institution of Automobile Engineers from time to time, to realize the importance of reducing the friction of the gases between the carburettor inlet and the cylinder head. It must be remembered that atmospheric pressure alone is available for forcing the working fluid into the cylinder upon the charging stroke and that the difference of absolute pressure at the two points above referred to must be kept as low as possible if a good volumetric efficiency is to be attained.

There are, it is true, methods of jockeying in order to compensate for inherent defects in a badly designed motor, but these are mere tricks to overcome an immediate difficulty. One for example which has been adopted by the Author in a certain case, was to design a special form of induction pipe to take advantage of the inertia of the pulsating gas and to alter the valve setting in such a manner that the pressure waves in the induction pipe assisted in the cylinder charging process. In a badly designed induction pipe, these pressure waves are expended in the direction of the carburettor causing blowbacks. Engine power has, therefore, to be expended in reversing the gas flow in the pipe from the carburettor to the manifold, and in addition difficulties of efficient carburation become manifest.

A ruling factor in the matter of gas friction is that of efficient carburation and a certain restriction must be embodied in the design in the vicinity of the carburettor jet in order to disintegrate the particles of liquid fuel effectually. Too large a choke tube entails fuel loss by reason of the lack of homogeneity in the mixture passing through the induction pipe, the fuel being carried forward in large drops. From the choke tube, the pipe should expand in a gradual taper in true stream line formation, as no advantage can be gained by using an abnormally large pipe with a small carburettor attached to it. Conversely, a large carburettor, as already shown, becomes inefficient with a low gas speed.

It may be stated in some quarters that a low gas speed can be used satisfactorily with certain types of instruments, but it is the Author's opinion that a gas speed of much below 200 feet per second is insufficient to secure that mechanical effect upon the fuel which is necessary with modern petrol. Such a gas speed corresponds to a water head of about 10 inches or rather more than one third of a pound per square inch. Much higher speeds are found in modern practice, a figure of three times this amount being not uncommon, but the resulting loss with such high velocities can be readily approximated.

Having determined the maximum speed of the gas through the choke tube, it only remains to reduce that speed gradually

throughout the intervening passages, but only gradually. Any sudden fall in velocity will be accompanied by carburation difficulties, due to the precipitation of the liquid, which will inevitably occur unless special means are provided to counteract it. Although a favourite modern practice provides an induction port passing through the water jacket, both to produce compact design and to provide the necessary heating, the Author is of opinion that a better method exists in the system he has devised for improving carburation.

Gas friction, like that of a liquid, depends upon the velocity of the fluid, the size of the pipe and also its continuity of direction. If, therefore, efficiency of flow is to be obtained, any changes of direction must be accomplished as easily as possible. When a volatile liquid is employed, the liquid will remain in a gaseous form even though it undergoes certain interference through variation of velocity or turbulence.

Petrol of the modern composition is, however, another matter, and owing to its complex nature, is very prone to return to its liquid state upon the least provocation. Petrol in an induction pipe is not all vaporized but only atomized, in other words held in suspension in a liquid form. Irregularities in the direction of flow cause precipitation which is most disastrous to the homogeneity of the mixture and this can only be provided against by vaporization.

The boiling point of the heavier fractions of motor spirit is considerably higher than that of water, anything up to 150°C., so that the temperature of the water jacket cannot be sufficiently high to cause vaporization of the heaviest fractions in many modern motor fuels. It is to the heavier fractions, therefore, that one must look for trouble.

The point at which this occurs is at the point of change of direction in the flow path and at such points a sufficiently high wall temperature must be provided.

Local heating of the induction manifold does not entail heating up the whole of the mixture and thus reducing the weight of gas per charge taken into the cylinder. It is not the *quantity of heat* provided which counts, but the application of a sufficiently high temperature at the correct points. If this is carried out in a scientific manner, the temperature of the gas entering the cylinder will be approximately that of the outside air, sufficient heat only being provided to equal the latent heat of evaporation of the fuel. A finely divided vapour is produced in a device of this nature, in appearance similar to tobacco smoke, and one need scarcely point out that efficiency of combustion results.

In spite of the fact that an internal combustion engine reaches in actual working a higher thermal efficiency than any

other type, yet the cost of its fuel compared with that of say coal, is so high, that worked on a fuel cost basis the petrol engine shows rather bad results. The question of fuel cost *per se* is outside the scope of this paper, but in the matter of efficiency, cost is the basis which the whole matter is reduced to in the long run. The cost of petrol, all are agreed, is an artificial one, but unfortunately we can see no real practical alternative at the present moment. So it behoves the designer to use the best means in his power to reduce the fuel consumption to a minimum. It is the Author's opinion that insufficient attention is paid to the important factor of light load consumption. Economy can be attained by using weak mixtures at high compression rather than by using a greater mixture strength at low compression as is generally the case, as instance, the former in gas engine practice. Fuel waste largely arises from loss at light load or when running idle, and this is mainly due to faulty carburation.

In order to overcome the tendency to starve the engine due to lack of volatility of fuel at low suction or low gas velocity, in the majority of instances an excess of fuel is passed into the induction pipe, only a portion of which is burnt efficiently, the remainder passing through the engine either in the liquid state or partially converted into CO and CO_2 during the process of combustion. There is no great difficulty in obtaining good fuel consumption figures at maximum power output with the majority of carburettors, but how seldom does such a state of affairs exist in actual practice throughout the range?

The most satisfactory and only reliable method of making fuel consumption tests is in conjunction with the accelerometer, and the Author has shown in some of his published tests how the power required to drive a car may vary enormously from moment to moment on the same road or track, and how this power varies from day to day.

This is due largely to wind resistance and rolling resistance. The former is a matter which is at the power of the designer to lessen in a certain measure. Suitable body contour should be insisted upon by the designer of the chassis, in other words the complete car and not only the chassis should be designed in the works, whenever economy of working is a feature to be aimed at. Elimination of wind resistance has become better appreciated in recent times, a stimulus having been given by the method adopted for the Treasury rating of horse power.

Whatever be the faults of the present formula, it has been the means of attracting the attention of designers, not only to the "efficiency of volume" of the motor, but what is equally important, the better design of body work from the point of view of resistance imposed. We may take it for a fact that in

still air, the wind resistance of a motor car body, at speeds up to 20 miles per hour, is negligible. The total resistance is represented by the rolling resistance, which on good roads is of the order of 70 lb. per ton. Weight here is the ruling factor.

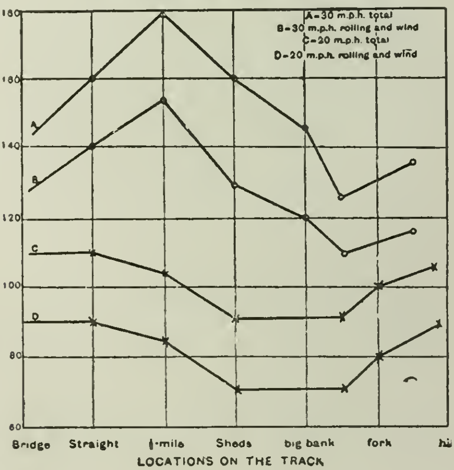
The figure of 70 lb. per ton will give the mass an acceleration of 1 foot per second per second, so that in making a test with the accelerometer, the reading would show 1 foot per second per second when the clutch is withdrawn.

Road resistance, however, varies enormously, and as a case in point the author's car proceeding along the road between Hounslow and Staines recently was observed. Part of this road has been relaid with an asphalte facing, the remainder being rough macadam. The throttle was set so that the car speed on the asphalte was 30 miles per hour, but on reaching the macadam, the speed dropped in a few seconds to 23 miles per hour, where it remained.

Brooklands tests made by the Author over periods extending to a week at a time, have shown how that even on the track, the total resistance not only varies from point to point on the

FIG. 1.

TYPICAL RESISTANCE VALUES AT BROOKLANDS

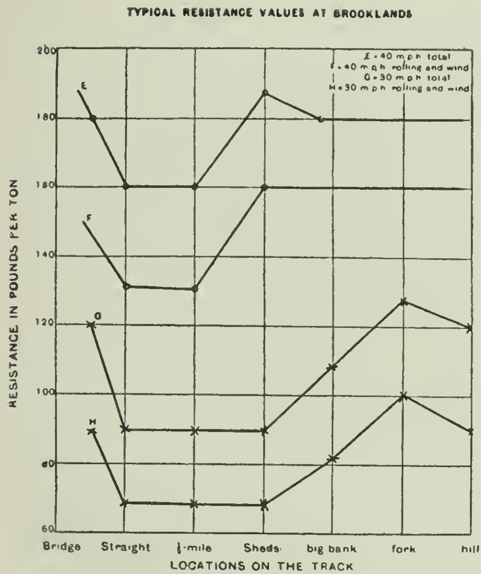


Curve C. shows the total resistance of the test car in pounds per ton at 20 miles per hour.

,, D. shows rolling and wind resistance. The difference is due to frictional loss.

Curves A. and B. show the resistances at 30 miles per hour.

FIG. 2.



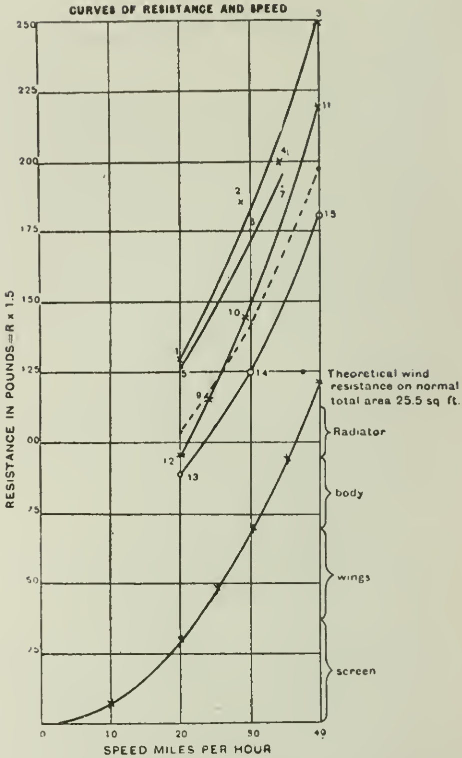
Curve G. shows the total resistance of the test car in pounds per ton at 30 miles per hour.
,, H. shows the rolling and wind resistance at the same speed.
Curves E. and F. show the resistances at 40 miles per hour.

track but also from day to day. In one complete circuit, the resistance is often 50 per cent. greater at one point than at another and it has been measured as high as 190 pounds per ton at high speeds on a touring car. Full details of tests have been given in *The Automobile Engineer* and in the American *Automobile.* During these tests the Author has been able to observe the resistance caused by the number plates and that due to eddy currents in the folded hood.

As a result of tests it has been found that suitable curvature of the body lines reduces the total wind resistance by 50 per cent. as compared with normal surface resistance. At speeds of 30 miles per hour a car of average form experiences a wind resistance practically equal to the rolling resistance. At higher speeds the wind resistance preponderates very appreciably.

Total car resistance is influenced by the question of balance ; and not only does this apply to the wheels, but also to engine parts and the propeller shaft. Very often one finds that propeller shafts do not run absolutely true, and loss of power results.

FIG. 3.



Curves showing resistance of the same car under different conditions during one week on Brooklands track.

As a matter of experience the Author ventures to suggest that the single jointed cardan shaft is liable to cause greater loss at high speeds than double jointed shafts. We must not lose sight of the friction due to sliding joints in the transmission but such loss is difficult to measure. The accelerometer will discriminate between engine frictional loss and transmission loss, but no further at present. Under the heading of transmission loss comes windage and it may be possible to divide these losses further by making tests in opposite directions, in a known wind.

Expenditure of power due to uneven road surfaces can only be met by the designer in two ways, the reduction of unsprung weight, and a system of springing such that the main mass of the car does not become affected by the wheels bouncing. Much attention has been given in recent times to the spring suspension

of an automobile and there is no doubt than the Lanchester system is holding its own. This subject has been well considered but there is still much to be learnt and appreciated. The subject has, hitherto, been considered rather from the point of view of the comfort of the occupants of the car than from an economical standpoint. A calculation could, however, be made, to show approximately the loss of energy entailed in jolting a heavy car body along the road. The fuel bill, when motoring in a rough country, such as is the Author's lot at present, forcibly brings home the fact that much fuel and money are needlessly wasted in causing discomfort to the driver and wear and tear to the car as a whole.

Discussion.

The **President** said that the paper which had been read was undoubtedly one of great interest to automobile engineers and to a certain class of engineers in other directions. For his own part, he could only speak from the point of view of the user of a car ; so that, to his mind, the points which the author had made represented a great deal of food for a most interesting discussion. The last few lines of the paper were, however, to him a very potent factor. As the author forcibly said, the fuel bill brought home the fact that much fuel and much money were needlessly wasted in causing discomfort to the driver and, he might add, to the passengers as well, and wear and tear to the car as a whole. He was sure that it would be the desire of the meeting that a vote of thanks should be accorded to Lieut. Brewer for his paper.

The proposal was put from the chair and carried by acclamation.

The following communication was read by the Secretary :—

Mr. F. Lamplough wrote : " As I am unable to be present at the reading of your paper, I take this opportunity of complimenting you upon the very able manner you have compiled your facts, which are so forcible and true that little room is left for discussion. I am of opinion, however, that the present method of carburetting is quite wrong, as in practice I find the heavier fractions rarely reach the cylinder, and when they do, pinking results, due to the high compression now generally used in European cars, and to the inferior spirit now being supplied.

" My last analysis of standard spirit showed an adulteration of 20 per cent., which means that this amount of spirit is noninflammable, and for some reason which I have never really understood any admixture of heavy fractions, such as light paraffin, is a fruitful source of pre-ignition. I have partially

traced the cause to a cracking action that occurs at high compression, which has no effect upon a pure spirit except to deposit carbon. When paraffin oil is present, decomposition of the paraffin fractions occurs and produces olifine, which is very inflammable, and leaves behind a gummy deposit detrimental to the motor owing to it having much to do with the increased carbonising that has taken place these last few months. This effect can be prevented in two ways—either by insisting on petrol companies sending out an unadulterated spirit, or by makers of motors reducing the compression, which would necessitate a larger bore of cylinder, although not necessarily a larger consumption of fuel, as I find motors that pink the most are prodigal in fuel consumption, while motors of the same cylinder calibre, with less compression, are more flexible and use less petrol on a given load. It is therefore obvious that pinking causes a considerable loss of power.

"With regard to carburetting I find that it is far more economical to let the fuel fall or gravitate in to the cylinder than to depend upon drawing it up from below, as even when using a perfect spirit the heavy fractions reach the cylinder only at high speeds ; at low piston speeds, throttled down only the light fraction rise, the heavier fractions washing back into the atmosphere owing to the dephlegmation of the mixture."

Mr. M. Holroyd Smith said the paper showed that while the author was a thorough master of his subject, he had been clever enough to avoid giving a definite solution of the difficulties that he raised. On that point he should draw swords with the lieutenant. He wished the author, instead of generalising and theorising so much, had shown how the difficulties which he pointed out could be overcome.

He did not know whether he had correctly understood what the author said on page 59 about the mechanical effect onthe fuel. If they turned the liquid into a gaseous state, and mixed it with a percentage of air, it seemed to him that " chemical change " was, perhaps, a better term than mechanical change.

One point that interested him was Lieut. Brewer's strong advocacy of clearance in the piston. His experience was of an early date and very rudimentary, but it might be helpful to others. In one engine that he made, finding the piston too good a fit, he adopted a very homely and elementary plan. He took the piston out of the engine when the weather happened to be very cold. The shop was heated by pans of burning coke, and he had the piston heated over the heated coke brazier until it got hot, and then tried to put it into the cylinder. He found that it would not go in, so he turned it down a bit, reheated it, and tried again. He skimmed the piston down until, while still hot

from the furnace, it would slide into the comparatively cold cylinder. Curiously enough, he found by measurement that the clearance that was necessary in the engine was in accord with the figures that the author had given.

He understood Mr. Brewer to say in one portion of the paper that he was advocating a piston perfectly smooth all the way down but in another portion he seemed to advocate a piston with a waist. He was not clear which of those two the author meant.

A point on which he heartily agreed with the author, and which had been a definite feature of his own practice, was the flexibility of the joints between the engine, the gearing, and the transmission shaft forward to the axle. He understood the paper to speak of two units. As far as he was concerned he should prefer three units, and he had always employed them. There was the engine, a flexible coupling between the engine and the gearbox, and another flexible coupling between the gear box and the back axle, and he should strongly advocate that form of treatment in all cases.

Another point that he was not quite clear about was the "rolling friction" and the "road friction." The friction of 70 lb. per ton looked to him rather low for tractive force if it meant the tractive force required with an ordinary load. It was about the tractive force necessary with a tramcar for starting a load. In the question of road friction or traction on the road they needed to differentiate between the friction required after the vehicle was set in motion and the power required for starting and overcoming its inertia.

Another question was that of springs, and with regard to that he had always been very emphatic. Some of the electric tramcars which he built in earlier days at Blackpool began to rock or tilt when running, and some of the passengers were actually seasick when riding in them. He then introduced what he would term inharmonic springs, that was to say, he took care that the springs would not vibrate at the same relation one to the other. By introducing auxiliary springs the vibration of which was of a different tone (if he might use the word) from that of the main spring, he was able to overcome the rocking, tilting, or wave action of the electric car. The same thing could be applied to motor cars going on a road, and he was quite convinced that, if inharmonic springs were adopted on motor omnibuses, riding would be more pleasant. Where motor cars or motor 'buses came down a hill, running free, they found that transverse corrugations were formed in the road surface, and the vehicle jerked up and down. If once a little dent was made in the road surface, the next car went into the dent and made it rather deeper, and it came out and made another little dent, and so on. He had noticed that emphatically that morning on Crouch Hill. In the

North of London the roads were deeply ribbed. He would not say that the employment of inharmonic springs would cure the difficulty, but it might partly overcome it.

He wished that Lieut. Brewer had given some instances of how to graduate the incoming gas into the engine and he agreed with the author, because, when a sudden turn was taken, butting against resistance and back again, objectionable resistance to the flow of the gases was created, but could be overcome by a better design.

Mr. H. Burchall said that the paper had interested him very much indeed, as three years ago running cost was one of the bugbears of his life. The author, however, sought to lower running costs by certain considerations during the designing period, but in the actual running of vehicles, although some of the problems were similar, they could not be tackled altogether in the manner described. His problem was to deal with a fleet of vehicles that could not be run cheaply, and all the scientific facts in the paper did not seem to help matters much, because the great cost was due to tyres and petrol. By far the most unsatisfactory item of cost was tyres, but that was a separate subject, and could hardly be considered in an engineering paper. It seemed to be a matter of luck more than anything else, and, after that, much depended on the driver. No amount of attention seemed to produce an adequate result.

Petrol consumption was more a question of control of drivers than perfection in carburetter adjustment. In running a fleet of vehicles of the same type, size and horse-power they could eliminate so many of the variables mentioned in the paper that the problem became to make each vehicle average a certain mileage to the gallon. Cars were delivered from the mechanics to the drivers who had charge of them, capable of doing, say, 25 miles per gallon, which the author mentioned in his paper as an average, but their mileage would immediately drop to about 16. That was highly unsatisfactory, and the cars were taken back for the cause to be discovered and remedied. In the hands of the mechanics they would still do 25 miles ; but immediately they were again in the hands of the drivers the consumption increased. The problem of making the cars give an adequate mileage per gallon was tackled from the engineering standpoint, but it did not produce good petrol consumption in practice, and therefore the problem was approached with a view to offering a bonus for low petrol consumption. Unfortunately, it did not prove to be feasible, because the saving in cost of petrol did not permit an adequate bonus being given to the driver to compensate for the trouble necessary to attain low consumption. He thought that drivers used petrol for washing their gloves, getting grease from their coats, and so forth, and kept their engines running when they ought to be stopped, to avoid the trouble

of starting them again. He had been averse to imposing a penalty on high consumption, but just when he was thinking seriously of doing so he took up some other work, and consequently had never put it into practice. He had heard since that a penalty system had been introduced, and had worked very satisfactorily. When a car fell below a certain mileage to the gallon the driver paid for the excess, and that made him more careful. He (Mr. Burchall) tried everything that he could think of to get consistently good results, and even went to the trouble of locking up the carburetter in such a manner that it could not be tampered with, because he had found that tampering with it was one of the chief difficulties. For rapid acceleration a fairly quick delivery of petrol from the jet was necessary, and drivers, if they had the opportunity, would enlarge the jet orifice with the tang end of a file! That could be penalised, but it could not be stopped, because the driver would never admit that he had tampered with the jet, and would always say that the fitters had made the alteration.

Petrol consumption was a very important point in fleet running, and he thought that the only way to overcome the difficulty was by absolutely preventing drivers from touching the carburetter. He was not aware of the method used by the London General Omnibus Company. He thought that it would be very interesting to know what it was, for he believed that they got quite a good mileage from their 'buses considering the loads carried. They adopted the policy of locking up the magneto in an aluminium box, and ordinary garage hands were not allowed to touch it. He understood that if the magneto was suspected of giving trouble an inspector must be called to examine it.

He was very interested in the use of the accelerometer as an aid to the reduction of road running cost; but, unfortunately, a scientific apparatus of that sort did not appeal to the directors of motor businesses. When he asked to be allowed to purchase an accelerometer with a view to reducing the running cost, his request was denied, and he was told that pretty scientific toys were not worth their money, and that he must do the best he could by other methods.

Mr. W. A. Tookey congratulated the author. He remembered a paper read before the Society by Mr. Brewer some eight years ago, dealing with the characteristics of motor fuels, a paper showing very considerable experience and research, and it seemed to him that the present one was equally good.

One or two points in the paper appeared to require some amendment, and one of these was the statement on page 53: "From theoretical reasoning the large engine working throttled down, *i.e.*, with reduced compression, should show a high fuel consumption." In a footnote the author called attention to the fact that under these

conditions—throttling—the compression ratio would not be reduced, but by the wording of the sentence one would be led to the conclusion that it was because of the reduced compression pressure that increased consumptions resulted. This, the speaker thought, was not the case. The actual compression pressure attained depended upon the volumetric efficiency of the engine, that is to say, the more the entering mixture was throttled, so the ultimate compression pressure was reduced, but the compression ratio being unvaried, theoretical considerations would suggest that the thermal efficiency would also remain constant. Experience showed, however, that the consumption did increase, as the author had stated, but the reason for this was that the throttling down increased the fluid resistance of the engine very considerably, and these resistances, in addition to the mechanical friction of the engine, naturally reduced the " mechanical efficiency " for at such times the I.H.P. was naturally much below the maximum of which the engine was capable. If, therefore, " theoretical reasoning " in this instance referred to thermo-dynamic considerations, the author should consider this point, for in the speaker's view the increased consumption that occurred was due to the increase of fluid friction and its greater proportion to the I.H.P. at light loads, rather than to any falling off in the theoretical thermal efficiency of the cycle due to the reduced compression pressure.

At the top of page 61 the author stated that there was no real practical alternative to petrol as a motor fuel at the present moment. This, unfortunately, was a fact. Probably everyone present knew that very many series of costly experiments had been carried out in the attempt to utilise kerosene for automobile engines, with little or no practical success as far as users generally were concerned. One of the main disadvantages of kerosene, and a very important one, was that under heavy loads, when the engine was working well up to its maximum, the temperature effect due to the heating up of the vaporiser and cylinders came into play, as well as the temperature due to compression, with the result that some at present undetermined chemical changes occurred which brought about pre-ignitions of a violent nature which prejudicially affected the running of the engine. These violent pre-ignitions created " bumping " similar to, but much more serious than the " pinking " already referred to that evening as being prevalent under certain conditions in petrol engines. Both these phenomena were primarily due to the use of unduly rich mixtures.

For several years past the speaker had paid particular attention to " mixture strengths," and it was his practice to compare the performances of all types of internal combustion engines on a mixture strength basis. The results of his observations had given much valuable information, for by expressing the value of a mixture in terms of British thermal units present in a cubic

foot of charge—combustible, air and residuals—comparisons could be instituted between engines working with petrol, kerosene, coal gas, producer gas, heavy hydrocarbon fuel oils, or, indeed, any gaseous or liquid fuel. By comparison of the mixture strengths with the mean pressure of the positive loop of the indicator diagrams, or of the calculated mean effective pressure on the B.H.P. basis (ηP) he had found that a very definite relation existed, according to the compression ratio of the engine and the instant of ignition. For example, in an engine with 100 lb. compression pressure with the mechanical details tuned up, correctly timed ignition, and with no excessive strength of mixture, every B.Th.U. present in a cubic foot of mixture would give 2 lb. of mean effective pressure on the I.H.P. basis. Similarly with a low compression engine, say, 50 lb., the ratio would be 1.6, and with a high compression, such as is used in the Diesel engine, 2.5.

It was, naturally, impossible to deal with this subject at length during a discussion of the present paper, but the speaker would emphasise the importance to every internal combustion engineer of finding out the mixture strength used in any particular engine, because upon the mixture strength the efficiency of the engine greatly depended, its working cost could be reduced, and its working power increased. He personally had found that both the petrol and kerosene engine were usually tuned up to give much too rich mixtures under full load conditions, and it was due to this that " pinking " in the one and " bumping " in the other occurred, the latter particularly being the reason why the author had found it necessary to record the fact that "no real practical alternative" to petrol could be seen at the present moment.

But there was another possible alternative fuel to motor spirit than kerosene and that was alcohol, about which the author in the present paper had been silent. There were several disadvantages to the use of alcohol in automobile engines, and one was that it could not be effectually used in an engine designed to use petrol. Alcohol required a much higher compression pressure, and therefore the engine had to be specially constructed. At the present time, also, it is impossible to obtain supplies at a price which would enable it to supersede petrol, and therefore comparatively little had been done towards the development of the automobile alcohol engine. Recent information published in the daily press, however, would appear to emphasise the desirability of utilising the large number of distilleries throughout the British Isles for the production of alcohol as a fuel for internal combustion engines rather than as an attraction and an incentive for mechanics to limit their operative abilities. There was no doubt that an alcohol engine could be successfully produced.

Mr. H. G. Burford offered the suggestion that it was impossible to treat the question of the running costs of motor vehicles in a general way as the author had set out to do. In his opinion, the question could be treated, first, as applied to the design; secondly, as applied to the construction; and, thirdly, they should consider the operating cost of the vehicle in the hands of the user. Very largely running costs were increased by defective engine, carburetter, or transmission designs, and in many cases the design was made simply with a view to low manufacturing cost and high selling price. As an engineer, he had been connected with the motor vehicle profession, and probably he and his friends who were present were about the first in this country who operated internal combustion motors. He regretted that the facts which had been accumulated for the last ten or twelve years had never been set out in a form that could be useful to people who were working in the motor vehicle industry to-day. The industry was largely governed by rule of thumb. Something was found out in the workshop that caused a certain operation, and that was about as far as they would ever get unless somebody would put down a formula that should give certain results.

The general question of running costs could be treated from scientific and detailed points of view by abler men than himself; it was so complex and varied, and there were so many applications that he would hesitate to summarise them in a paper of the kind that they were discussing. The author had very carefully put before them the question of gas friction, lubrication, and other details. He would like to see some authoritative work placed in our libraries, so that those who came after them could see, as they could in ordinary engineering matters, that if they did certain things certain results would follow. He and many other engineers in the motor industry were looking forward to that class of work. The question of fuel was, of course, a very important one with regard to running costs, treating the question from the operating point of view.

One speaker rightly said that the question of petrol consumption was one which depended very largely on the operator. He (Mr. Burford) thought that due care was not given to the fuel levels in the carburetter. He thought that they would find, with regard to nearly 70 per cent. of the waste that went on now in connection with the use of motor vehicles, that the oil level or the petrol level was not studied, and, consequently, there was a constant leakage and wastage nearly all the time the vehicle was standing.

The question of tyres had been a very big factor from the early days when they paid something like 4d. per mile run for rubber tyres. To-day he had had an offer from a rubber manufacturer

of a contract at a halfpenny per mile, so that the rubber tyre question had gone down to a very low commercial basis.

With regard to the question of road surfaces, the statement made in the paper in reference to resistance and road friction opened a very wide subject, and doubtless they could spend many hours in getting useful data and making comparisons. The author had made use of very interesting and, he should say, good data with regard to the clearance of pistons. In the manufacture of internal combustion motors very many questions arose as to the clearance. Nothing has been said about the length of the piston, but that had a good deal to do with the question of clearance, and many other factors entered in, such as the quality and composition of the cylinders. All those things must be taken into account when determining the clearance necessary for pistons. Before they could arrive at useful data they must have a record of the clearances required with certain materials, because it would be fatal to take the clearances given in the paper for general use.

Mr. Wm. P. Durtnall said that the question of the running costs of motor vehicles was of the utmost importance to engineers and commercial men, who in this country had to import oil or petrol.

He had made a very close study of the road automobile for the last fifteen years, and he thought engineers should give much closer attention to the efficiency of petrol motors than they did at present. He hoped shortly to bring out an engine that would show a much greater efficiency than they had at present with the "Otto" cycle. He had had considerable experience with many types of internal combustion engines in the automobile and other industries, and he could not help noticing what a great loss was going on at the present time from the thermo-dynamic aspect by still retaining the use of the method of atmospheric carburation, with its variations of velocities, temperatures, etc. There was also the complication of having to supply the extra temperature required for ignition by a magneto or otherwise, even if they got the proper gas, which, as the author had pointed out, was very doubtful. The question of using an engine that would take in a charge of air only and would fire, self-ignited and timed, a charge of gas made from the hydrocarbon, whether it be petrol, paraffin or the heavier oils, was, he believed, perfectly feasible, and he hoped to show such an automobile type of engine in operation in London before many months. By doing away with the carburettor and ignition they did away with two of the most troublesome items, and, instead of a thermal efficiency in an "Otto" cycle engine approximating to 28 per cent. in a good engine, they would have a thermal efficiency approximating to the Diesel

cycle of 40 or 45 per cent. That would effect a great reduction in fuel cost, and consequently in the running cost of automobiles.

The author did well to draw attention to loss in transmission. That was a matter which had received considerable attention from himself and many others. The most modern cars with which he was acquainted had been constructed with a view to keeping the engines always loaded, and consequently they were working, in his opinion, under the very best conditions. About seven years ago he designed and built a motor 'bus shown in

FIG. 4.

Fig. 4. In dealing with road traction resistance Lieut. Brewer gave it as 70 lb. per ton. The motor 'bus that he designed was built with ball bearings on all axles and the finest material, vanadium steel, that could be got. It was towed along the Victoria Embankment by a lorry at twelve miles an hour, and the tractive effort was equal to 90 lb. per ton. He therefore thought that the author's figure of 70 lb. per ton was rather low, taken as an average. He had known vehicles to go up to 120 lb., and even 150 lb. per ton, at 12 miles an hour, on ordinary level macadamised roads. Many points had to be considered, such as the diameter of the axles and the wheels, the weights of the wheels, and so on, especially the first-mentioned.

He had endeavoured to avoid heavy mechanical transmission losses by the adoption of electrical power transmission. In the latest designs they were able to use a small engine kept loaded at constant revolution speed. In his early motor 'bus, 1907, taking the tractive effort at 12 miles an hour, it needed about 10 B.H.P. to make the vehicle travel at that rate on the level macadamised road of the Embankment. Taking a ten-hours' day working on

level roads, it was equivalent to 100 horse-power hours. They put in a 42 brake horse-power engine, in order to meet the ordinary road traction conditions which were found at Muswell Hill or Highgate Hill. They had an equivalent of 420 horse-power to meet the traffic conditions for grade climbing during 1 or 2 per cent. of the life of the vehicle on the road. On that point he thought that Lieut. Brewer did well to point out the effect of light load running efficiency, especially with regard to the ordinary running costs of motor vehicles ; it really represented a very large figure not yet thoroughly appreciated. In the touring types of car they had also to put in an engine that would always run at constant revolution speed and full load. They put on an engine capable of generating the horse-power hours for a ten-hours working day. The variable power required for grade climbing, starting and acceleration was obtained by the use of the small Edison storage battery, and when the car was standing or running down grades the kinetic energy of the car and load was utilised instead of being wasted in friction heat on the brakes and brake-shoes. At the same time the engine was always working at full load and revolution speed, and consequently under the best thermal conditions. The adoption of some means, electrical or otherwise, by which there could be a flow and return of energy between the prime movers and the axle of the car itself, he believed, would do away with much of the loss in the everyday working of pleasure and commercial cars.

Reply

Lieut. Brewer, replying to the discussion, said that he was afraid that there was an impression that the title at the head of the paper did not sufficiently explain what was inside. That title, however, was not his. What he really meant to imply in writing the paper was that he was only going to deal with certain factors which governed the working cost, these being such factors as were under the control of a designer who was desirous of going into the whole matter from a purely technical point of view, rather than looking at the matter from a commercial standpoint. Mr. Burchall showed that, however well a machine might be designed, and however good it might be when it was originally handed over to a driver, it was rather outside the scope and power of the engineer who originally planned the scheme to insist upon his ideas being carried out in actual practice. Engineers knew how extremely difficult it was to control the average working man, whether he were a mechanic or a motor driver, and there were only certain more or less sordid motives which could be resorted to in order to keep the working costs down to what they ought to be. It was not a question so much of the brains of the

designer, after the machine was completed ; but he thought that it behoved engineers to put their best brains into a problem, whether it be the designing of a taxicab or a commercial vehicle, or a racing car, so that they knew that when they had turned it out it was capable of such and such a performance. It was not sufficiently satisfactory for them to see their machines on the road doing, for example, 15 miles per gallon when they knew that they would do 25. Engineers set out with a certain object in view, and if they had any enthusiasm at all they reached it. It was for somebody else and not the engineer at all to look after the actual running cost from a commercial standpoint, for he thought that the same man could not be a designer and a commercial manager of a concern which was operating motor vehicles.

His object in putting a few facts before the Society was to get a discussion and obtain the ideas of others who had been working in the same field on certain problems, which, he thought, engineers had not thrashed out sufficiently. He had passed over many other most important problems because, of course, they could not discuss everything in one evening. Furthermore, as he had pointed out, certain of the problems had been well discussed, and they had certain definite data which were undoubtedly very useful. In addition to the data which we had in this country there was an extremely useful amount of information available from America which, in itself, was the result more of practical application than of theoretical considerations. But, at the same time, Mr. Burford asked them, or asked the automobile world generally, for information which would help the designer. Well they had a good deal of information, but at the same time the automobile industry passed through so many stages that they could not put it down as an axiom that what was good to-day would hold good to-morrow. The steam engine had gone on through many years of development, and in its present state of perfection there were certain recognised standard data which, more or less held good. Engineers did, however, by their meetings and discussions, endeavour to get into their proceedings a certain amount of information which would help those who came after them in treading the tracks which had been well worn. Mr. Holroyd Smith had very rightly, he thought, asked for something more definite than he (Mr. Brewer) had been able to give him. He might tell Mr. Holroyd Smith that in war time it was exceedingly difficult to get at one's data. He did not want him to go away with the idea that he had not got data, but he had been unable to bring them forward to-night.

Although the curves were on a very small scale, they were well worth study. Considering for a moment a few of the points used in this discussion, with regard to the question of resistance, he had given 70 lb. a ton as being a mean figure for rolling resis-

tance. Seventy pounds was not a hard and fast figure by any means, and that was one of the points that he wanted to bring out that evening. They might put down as a result of experiment, or as a result of general all-round commercial observation, that a motor 'bus or a lorry running upon anything like a macadamised road would have a rolling resistance of 90 lb. or 100 lb. a ton, and they might make certain tests and trials, and put the vehicles on the road as having passed the test ; but what he wanted to bring out clearly was that even in the best ordered system, or in the finest commercial house in the world, the conditions varied so enormously from time to time and from day to day that they could not always blame a driver for not getting the results which the machine ought to give. The reason was that the resistance of the machine undoubtedly varied, and its mechanical efficiency varied too, almost from moment to moment, and people who complained, for example, about a commercial vehicle giving a bad fuel consumption, or giving bad results, made complaints in a haphazard manner, without making further investigation. He mentioned in the paper the use of the accelerometer ; this was not an expensive piece of mechanism. The accelerometer would, anyhow, eliminate one factor which came into play when they had working costs to consider. One very frequently heard that running costs and wear and tear were high without being able to investigate the reason why in a ready manner. The usual procedure was for somebody more or less in authority to go over a vehicle and find faults, and promptly start making adjustments to the carburetter or the magneto, without realising the fact that the test or the series of runs might have taken place over a road which lent itself to high fuel consumption.

He wanted to go into one detail in explanation of what had been raised by one of the speakers. He believed that it was Mr. Holroyd Smith who said that he (the author) did not define what he meant by rolling resistance, and what he meant by road resistance. To his (the author's) mind there were two distinct resistances experienced on a road. There was the actual rolling resistance of between 70 and 90 lb. per ton, which figure obtained with a tram on rails or any rubber-tyred vehicle on a smooth road, and, in addition, there were road resistances which were experienced at anything like a speed, and which were entirely apart from the primary rolling resistance, and were due to the presence of the differential in the back axle causing the vehicle to spin on bumpy roads. The wheel which was spinning at one moment was churning off its tread the next moment. Such resistances as he had enumerated were undoubtedly very marked, and many of them in high-speed work were obviated by the use of a solid axle. Those who had tried high-speed work with any

degree of accuracy knew that many of the resistances could be reduced by certain " dodges." He did not think they were fully alive to the enormous loss of power which resulted from wheel spin alone. He had briefly referred to the loss of power through jolting. Obviously, any mass which was violently accelerated in a vertical direction with sufficient rapidity must be a consumer of power. He was sorry that nobody had really remarked on the question of the weight of a back axle, because he believed that there was very great scope for discussion in that direction. When they looked to certain American vehicles which should be nameless, they saw that their unsprung weight was extremely small, and for some reason, which at the moment was more or less unknown to him, the unsprung weight seemed to remain intact under very great abuse, and if it could remain intact under those particular conditions he did not see why they should not take a leaf out of the American's book and reduce their running costs by reducing the unsprung weight, because undoubtedly a good deal of power was wasted in that direction.

Mr. Holroyd Smith had not quite followed him on the question of what he intended to imply in connection with the choke tube of a carburettor. Discussing the fuel aspect for a moment, the point he wished to impress was that, as they all knew quite well, liquid fuel could not be converted into a homogeneous mixture unless certain conditions were maintained. What he said was that if they had a limiting lower value for the air velocity, a certain mechanical action of the air stream on the fuel stream resulted, and, if that mechanical action was carried out as it should be, the fuel stream was disintegrated, as, for example, in the case of the syringe which was used in greenhouses for certain plants where the spray issued from the nozzle in a practically invisible form. That was a purely mechanical action. There was no question of chemical action coming in at all. Under many working conditions, as, for example, when they had a large motor running under low load conditions, the real loss was due to the lack of homogeneity in the fuel, and that was a direct result of mechanical action not being carried out above its lower limiting factor. In other words, if they could have an elastic choke tube and induction pipe which adapted itself in sectional area to the demands of the engine, a much more economical motor would be possible than existed at present. One of his arguments throughout the whole paper—and he was glad that it had not been refuted—was that engine size was not a direct measure of fuel consumption in this country. He would not be happy in making a definite statement as to why it should be so, but undoubtedly it was a fact that, if rather more light could be thrown upon the subject, it would help engineers very much in designing an engine. There were certain apparently

complicated statements in the paper which he did not think could really be taken absolutely at their face value. They required more study and more actual data, in order that they might be set down as axioms in engine design. There was one point, however, that they were quite sure about, and that was that the small so-called high-efficiency motor was as great a fuel consumer as the big motor. For example, a 15·9 H.P. motor in the ordinary way burned nearly as much fuel, if not as much, as a 40 H.P. motor under R.A.C. rating.

A point with regard to construction had been raised by Mr. Holroyd Smith. He (the author) had really only discussed a two-unit motor as being a manufacturing proposition and one in which there was less likely to be undue loss due to faulty or cheap methods of assembling. When they considered engines designed from a purely commercial standpoint there were certain sacrifices which had to be made , and although it might be very nice to urge a three-unit construction, and although one could make a three-unit construction reasonably cheaply, yet the possibility of error and the possibility of expensive running always existed in a multiplicity of units. With regard to springing, it was extremely interesting to know that the inharmonic system of spring suspension was instrumental in eliminating the rocking of a tramcar. Many machines were made now with various types of springs with different periods, and he thought that engineers were making progress in that particular direction. Not only did they use springs of different periods, but systems were interposed between a spring of a certain period and the axle in order to set up oscillations of a different period, so as to damp out, more or less, the main period. He did not think that they were anywhere near the end of the springing question at the moment, and it seemed to be rather a fight between inharmonic suspensions and the Lanchester type.

As to alternative fuels, he would like to have an expansion of the Tookey formula to show, if possible, exactly what variation in B.Th.U.'s per cubic foot of cylinder volume would be necessary as between, say, an oil and a volatile fuel and a gas. From Mr. Tookey's remarks it would seem that where an oily substance was present, the great difficulties which they had all experienced with oil engines would be found with regard to bumping when the engine was heavily loaded for any period. Possibly the mixture strength factor should be modified in some way to avoid such difficulties.

With regard to the use of alcohol, many engineers had had weary times in connection with this fuel. He thought that the great difficulty with alcohol, at least in the early days, was in the varying results obtained from moment to moment. Whether or not the variation was due to the fact that water was soluble in

alcohol, he did not know definitely, but he rather thought that it was, alcohol must be carefully manipulated for this reason. The liquid itself absorbed moisture from the atmosphere, and under working conditions it is probable that the contents of the tank were not quite homogeneous, and at one moment a useful hydrocarbon reached the carburettor, and at another time a good deal of water would be present, causing a great deal of trouble in burning. Those difficulties would not occur in a laboratory which was laid out for the purpose. He did not think that that point had really been made by those who had experimented in the laboratory only. Certainly, on the road the difficulty was very great.

Mr. Burford had been good enough to point out that the subject under discussion should have been treated under three heads, and certainly it should have been, and probably under many more ; but he (the author) had already explained that he had only attempted to deal with it from a scientific and designer's point of view, and that only in one or two small details. An engineer was so often under the thumb of a board of directors that he could not do what he would like to do, and that made it extremely difficult for a man to do himself justice when told to design a job to a price. He had to sacrifice certain things to the works manager. The engineer would like to put a ball bearing in a certain place, but the works manager would eliminate that item on the score of cost, and the result was that there was trouble and the machine would not operate in the manner originally intended. Then the engineers were blamed by the customer, who wanted to know why the car refused to change speed. The only answer was that the works manager refused to allow a ball bearing when the engineer wanted it. It was a very unhappy state to be in, but that was the position at the moment.

He was glad to say that Mr. Durtnall had touched on a very favourite topic of his on which he was well qualified to speak, and that was the question of storage of energy and transmission. That was one of the difficulties which they had to encounter. As he had pointed out in the paper, 9 H.P. was quite sufficient for ordinary needs, but it did not get them past a man who was blocking the way. He thought that Mr. Durtnall's system might prove valuable as if one had a little reserve energy which could be drawn upon without the capital cost being too great, it would enable the designer to surmount many of the difficulties which had been mentioned in the discussion.

13*th April*, 1915.

NORMAN SCORGIE, M.INST.C.E., PRESIDENT, IN THE CHAIR.

MAIN ROADS PAST AND PRESENT, AND MODERN METHODS OF CONSTRUCTION AND MAINTENANCE.

By FRANK GROVE, M.Inst.M. and Cy.E., Assistant County Surveyor of Surrey.

THE difficulties of satisfactory road construction and maintenance in this country have in recent years reached a very acute stage, which has been brought home with much force to all road engineers and others interested in the work, and in a particularly unpleasant form to the ratepayer who has been called upon to meet the increased cost, the extent of which has caused him no little alarm. This paper gives an outline of the inception and development of the road system in this country, and indicates in detail some modern attempts to cope with traffic ever increasing in weight and numbers.

HISTORY OF ROADS IN ENGLAND FROM ROMAN TIMES.

We are told by various writers that the Romans, the greatest roadmakers of ancient times, were noted for the excellence of their roads, which were laid out in straight lines from point to point, often regardless of obstacles which might have been avoided, and have never been excelled in solidity of construction. Their general straightness may perhaps have been due to convenience in setting out or to their being laid out in a line with some prominent landmark. Some of them still remain, forming the foundation of more modern roads. Their general method of construction consisted of a foundation of one or several courses of flat stones laid in mortar, with a surface of pavement blocks laid on concrete and jointed with mortar, and were often three or more feet in thickness. For the small amount of traffic they had to carry their construction would seem to have been unnecessarily substantial. The usual width of the paved portion of the road was about 14ft., with unpaved ways on both sides about half the width of the paved road and separated from it by raised stone edgings. The surface was sometimes made of hard concrete, pebbles, or flints set in mortar, and sometimes in clay and marl. Where inferior materials were used the surface of the road was made higher and rounder in cross section.

The Roman roads were in use down to the Middle Ages, but

were not regularly maintained, and gradually fell into disuse. Their materials were used for building, and they were partly ploughed up so that they are now mostly unidentifiable. Later roads in England are more or less tortuous, but the Roman straightness was copied to some extent in France about the beginning of the eighteenth century, when new roads were constructed by the Government of that country, known as "Routes Imperiales," afterwards designated "Routes Nationales," and supplemented at a later stage by the construction of roads of secondary importance called "Routes Departementales," and branch roads known as "Routes Communales."

During the Middle Ages there was practically no vehicular traffic, and comparatively few new roads were constructed. Those that were made fell far short of the Roman standard, and for the most part cannot now be traced. They were practically dependent upon charitable bequests for their repair, and these bequests, although usual upon specified roads, were sometimes made for the repair of unspecified roads, and generally took the form of gravel or other material for repairs. Guilds largely contributed to the maintenance of the roads, and monasteries and the clergy also assisted.

Many ways were constructed during the Saxon and Norman periods, the most interesting of which were those by which pilgrims travelled to the various shrines throughout the country, traces of which still remain. In Tudor and Stuart times high ways, hollow ways, cause ways, and other ways were made, and took their names from their method of construction, which was very primitive, while they were narrow and, as a whole, badly kept.

In the fourteenth century vehicular traffic was not unknown, but it did not become general until the middle of the sixteenth century, when public road vehicles were first introduced. The roads at that time, however, were most unsuitable for such traffic. Before the end of the sixteenth century coaches became the general means of conveyance among the wealthy classes, and stage coaches appear to have been introduced towards the middle of the seventeenth century. At first there was a great outcry against their introduction, and it was some time before the old method of personal conveyance by saddle-horse became obsolete, and stage wagons were substituted for pack-horses.

At the beginning of the seventeenth century, owing to the increased use of vehicles, the Legislature had to choose between adapting the roads to wheeled traffic or adapting wheeled traffic to the roads. It chose the latter course, with the result that numberless Acts of Parliament were passed restricting the number of horses to be used in carts and wagons, the weights to be carried, and the widths of wheels. The greater the width of tyre the less toll had to be paid, the theory being that broad

wheels tended to preserve and consolidate the roads, whereas narrow ones cut them up, thereby increasing the cost of their upkeep. Each parish had to maintain its own roads by statute labour, and this no doubt accounted largely for their bad condition. The road problem was eventually solved by adapting the roads to the traffic by the passing of the Highway Act of 1835 (referred to later), which at one sweep removed most of the restrictions on traffic.

Down to the middle of the eighteenth century the roads then existing were hardly worthy of the name, and were for the most part hilly and tortuous tracks, because low-lying ground was never crossed if it could be avoided. Local taxation was the sole method of raising money for absolutely necessary repairs, and no doubt the standard was a low one. The establishment by law of numerous turnpike trusts, peculiar to this country, enabled gates or barriers to be set up, and tolls levied upon the persons using the roads, the money thus obtained being utilized in their maintenance and improvement. The system was cumbrous and the persons appointed to administer the tolls so incompetent that very little improvement was effected. The turnpike trusts added largely to the number of hilly roads, and no attempt was made to obtain expert advice or skilled labour in the execution of the necessary repairs. Such materials as could be most readily obtained were heaped upon the middle of the roads without any attempt being made to consolidate them. The roads thus became so convex that the only safe place for the traffic was along the centre of the road, and the wheels of vehicles pressing against the sides of the roads caused deep ruts and pushed the materials into the ditches.

This state of affairs existed until the beginning of the nineteenth century, when Telford and Macadam directed their attention to the construction of roads and brought scientific principles and regular system to bear upon their construction and repair. Their methods were very similar, including thorough drainage, the use of properly broken stone, and the adoption of a uniform cross section of moderate curvature. Angular broken stone was spread evenly over the surface and finer material sprinkled thereon, so that the traffic passing over the road would consolidate the material and form a hard, smooth surface. Telford paid particular attention to the foundation, and his name is associated with a pitched foundation, which he did not always use, and which closely resembled that which had long been in use in France. Macadam, however, disregarded it, contending that the subsoil, however bad, would carry any weight if made dry by drainage and kept dry by an impervious covering. Macadam was chiefly engaged on the repair of old roads, and the improvement which he effected in road management and main-

tenance was great and lasting. His method of repairing roads became general, and with the addition of the use of a roller to consolidate the material is still chiefly employed on the majority of roads in this country to-day. The process of rolling the newly laid material appears to have been adopted about the year 1830, but it was some years later before the practice became general, chiefly because of the expense entailed. The steam roller made its appearance about the year 1863 and in the first instance was an adaptation of a form of traction engine.

In 1835 an Act of Parliament was passed to consolidate and amend the laws relating to highways in England. This placed the burden of upkeep of the roads on each parish and gave Justices of Quarter Sessions power to unite parishes into districts. This Act related to the appointment of Surveyors of Highways and Boards of Management, and authorised the erection of guide stones and posts at cross roads and other places. The Surveyor was empowered to make, assess, and levy a rate in order to raise money for the purposes of the Act. Much of this Act is still in force and forms the basis of highway law in many respects at the present day.

With the great development of railways in the Victorian era the traffic temporarily left the roads and this resulted in their neglect, although strenuous efforts appear to have been made during the last days of coaching to improve the roads in order to keep the traffic upon them. The Turnpike Trusts had, by this time, become heavily in debt owing to a large decrease in tolls, but in spite of this they struggled on for a considerable period, and it was not until the Highways and Locomotives (Amendment) Act of 1878 was passed that their fate was eventually sealed. This Act gave the County Authority power to enforce the repair of roads, and stipulated that all roads dis-turnpiked after 1870 should become main roads, half the expense of maintenance being thrown upon the county rate. This Act also empowered the County Authority to declare ordinary highways to be main roads.

Since April 1st, 1889, the appointed day referred to in the Local Government Act of 1888, main roads have, in general, been wholly maintained and repaired by the County Council. Urban Authorities, however, were offered the option of "claiming" to retain the control of the main roads in their districts, the County Council making an annual payment in respect thereof. This Act also enabled the County Council if so disposed to delegate the control of the main roads in "unclaimed" districts to Local Highway Authorities, making an annual payment out of the county rate towards the maintenance, repair, and reasonable improvement of same. Some County Councils adopt the system of direct management for the main roads whilst

others adhere to maintenance through the Local Authorities, and opinions differ as to which is the better method. In the County of Surrey, where the Author's experience covers a period of nineteen years, a dual system is in existence, although only a small mileage is directly maintained. This is no doubt very largely because the County bordering on the Metropolis consists for the most part of Urban Districts where direct management would be difficult, inasmuch as the County Council is liable only for such scavenging as is necessary for maintenance, whilst the Local Authority is responsible for any sanitary scavenging necessary for the convenience of the inhabitants.

Traffic Requirements immediately prior to the Introduction of Motor Vehicles and Details of Road Construction at that time.

Towards the end of the nineteenth century, and just prior to the introduction of the self-propelled vehicle, a general improvement of the main roads had been effected. This was no doubt in a great measure due to the general improvement of the means of transport both as regards passengers and merchandise, and also to the increased popularity of cycling which had then reached its zenith. The spreading of the cost of maintenance over a larger area, and the more skilled supervision provided by the County Councils, also tended to a more uniform and better standard of maintenance. The surface of the Surrey roads consisted mainly of local gravel, flint and other local stone, of which there was an abundant supply within the borders of the County, but the majority of the roads were sadly lacking in good foundations. The latter was mainly an aggregation of gravel and other local materials used from time to time in the various coatings and laid upon the natural subsoil. The traffic, however, on some of the more important trunk roads had grown to such an enormous extent that it had become necessary to substitute a tougher material for the flint and local stone formerly used. This necessitated the use of various kinds of granite, basalt, limestone, &c., all of which had to be imported into the County from the Midland and Western Counties and from abroad, and consequently added very considerably to the cost of upkeep.

The principle of repairing the roads at that time was entirely that of the water-bound macadam method. The surface of the portion of road to be repaired was first loosened either by means of hand picking or of a scarifier attached to a steam roller. The loosened material was then carefully raked until a regular camber with a fall of one inch in two feet from the centre to both sides was obtained. In low-lying and damp places a little more fall was given and in dry open places and on hills a little

less. Any depressions or soft places were made up with new metal, usually large unbroken flints. The new material carefully broken to a gauge of about two inches was then, under the superintendence of a competent spreader, evenly spread over the whole width of the carriage-way to a depth of about three inches or more and rolled dry without crushing the material, after which binding material such as clean sand, fine gravel, hoggin, or sometimes road sweepings was sprinkled thinly upon the partially rolled surface. Water was then applied and the surface again rolled. Labourers were then employed to sweep the surface until the resultant slurry completely filled all the interstices between the stones and the new metal became thoroughly consolidated. The usual weight of the roller used was about ten tons. It was found that the surface of a flint-road, if properly attended to, continued to improve under traffic for some time after the metalling had been applied, whereas the surface of a granite road quickly became uneven and steadily deteriorated from the day the steam roller left it. To obtain a more even surface, granite of a smaller gauge than two inches was tried, but this smaller gauge was used only after a sufficient crust had been formed by the use of granite of a larger gauge.

The autumn or the early winter months was considered the best time of the year to carry out the repairs, as depressions and soft places could be more readily detected when the roads were in a wet state, besides which the surface could be more easily scored and the new material more readily worked into the old. The materials for the annual repairs which were, as far as possible, obtained, carted, and in the case of flints, broken during the summer months when the roads were hard, were deposited in depôts by the side of the road nearest to the point where the material was to be applied. Wherever possible the repairs were executed in long lengths in preference to patching, which is never a very satisfactory method of repairing roads.

The roads were divided into lengths of from two to five miles and permanent roadmen called "lengthmen" were employed throughout the year to scrape and sweep the surface, and the road sweepings after being collected at the sides were removed as soon as possible, or distributed over the roadside wastes. Small quantities of patching material were stored in depôts at convenient intervals so that in case of hollows and weak places appearing they could be quickly filled up and attended to by the lengthmen before further damage was done. During periods of long drought the surface, more especially in Urban Districts, was watered to prevent its breaking up and being worn to dust under the constant traffic. Flint roads break up more quickly than granite under continuous and heavy traffic in dry weather, but whereas watering or damp weather improves a flint

road, continuous rain or the constant flooding of a granite road by excessive watering does more harm than good. The water collects in the depressions or "pot-holes" and renders them softer, so that wheeled traffic increases their depth, and if not quickly attended to a very uneven and bumpy surface is the result. Frosts and extraordinary traffic also contribute largely to the break-up, whilst trenches for sewers, gas, water, and other mains damage the roads extensively and can almost invariably be traced for a long period, sometimes years, after they have been filled in, however carefully this may be done. During the Spring and Summer months the lengthmen are employed in keeping the side channels clear of weeds, cleaning out the ditches and grips, trimming verges, breaking flints, etc.

During the period under review very little road construction was carried out owing to the very complete network of highways in existence. Where, however, it became necessary to provide new foundations the material usually employed was hard core consisting of old concrete or brick rubble.

The thickness depended upon the nature of the subsoil, six inches being considered sufficient on chalk or gravel, increasing to twelve inches on clay and wet soils, with three inches of ashes on the bottom to prevent the clay squeezing up into the hard core during consolidation. The finishing coat consisted of gravel or flints six inches thick, laid and consolidated in two separate thicknesses, the material for the bottom layer being of a larger gauge than the top coat.

Effects of Motor Traffic on the old type of Roads and Methods employed to cope therewith.

Just before the dawn of the present century the lighter form of self-propelled vehicle, which had become legalized by the Motor Car Act of 1896, made its appearance, and although at first the growth of this class of traffic was slow it was not long before its presence was forcibly felt. Cycling had begun to wane but this was more than compensated for by the rapid and unparalleled improvement in the transport of passengers and goods, which not only brought about a change in our highway system but also robbed the railways of a monopoly which they had enjoyed for a number of years. It soon became necessary to permit an increase in the speed of motor cars from 12 to 20 miles an hour, which was done by the passing of the Motor Car Act, 1903. This also gave the Local Government Board power, on the application of the Local Authority, to reduce the speed to 10 miles an hour on certain specified lengths of highway, and authorised the erection of sign posts to denote dangerous corners, cross roads and precipitous places with a view to the safety of the public.

Traction engine and other traffic had also increased very considerably, the use of the former being no doubt greatly extended in consequence of the rates of freightage by railway remaining very high and as a result of mechanical road traction becoming cheaper than horse traction, a certain amount of which was displaced from the roads. Following in the wake of the automobile for personal conveyance came the light motor vans for the delivery of goods and also the heavy motor car or lorry with its accompanying trailer attached. These were made legal by the Heavy Motor Car Order of 1904 which arose out of the Act of 1903.

It was not long before the roads as then constructed were found to be entirely unsuitable for this class of traffic. Many long lengths of flint roads where the traffic was heaviest were converted into granite roads, whilst numerous bridges had also to be strengthened and in many cases entirely rebuilt to make them sufficiently strong. The repair of the roads in half widths became a necessity to prevent horsed vehicles carrying heavy weights, and motor cars with soft tyres, being compelled to pass over lengths of unrolled metal, although the repairs could more easily and efficiently be executed if the whole width were coated from side to side. The rapid growth in the number of motor cars and pleasure vehicles using the roads, especially at week-ends, did considerable damage to the flint roads in consequence of the sucking action of the rubber tyres drawing the small metal to the surface and the ordinary traffic converting it into a layer of sharp fine grit whilst at the same time the large metal below became loosened. On macadamized roads small hollows and depressions were also quickly formed. It was no uncommon sight to see a good and apparently sound road after a fine week-end very badly damaged and tracked, rendering constant attention necessary. Motor traffic was also responsible for the numerous complaints received of the nuisance caused by dust and the bad condition of the surface. The dust nuisance became so acute that house property abutting on the principal thoroughfares depreciated to a very appreciable extent, in some instances as much as 20 to 25 per cent. in letting value, whilst large numbers of houses became empty from the same cause. The enjoyment of the roads by pedestrians, cyclists, and others, more especially along lengths of road having no footpath, was greatly interfered with, and ratepayers complained that large sums of money were being spent in maintaining the roads for foreign motor traffic to use and destroy. Traffic statistics taken at the time shewed that the main roads in Surrey were more used by motor cars than in any other county around London. In no county had the growth of traffic been more marked or its destructive effects more felt.

The problem of dealing with the dust nuisance and at the same time decreasing the damage done to the surface in order to preserve for the public the use and enjoyment of the highway to which they were entitled was very pressing and difficult inasmuch as it had become necessary to make the roads strong enough to carry traction engines and heavy motor cars, and at the same time smooth enough for fast motor car traffic and cycles. It was recognised that, given roads of certain materials and construction such as granite setts and wood paving, the dust nuisance would disappear, but the cost of such roads was quite beyond the pockets of the ratepayers.

With a view to mitigating or preventing the dust, experiments were made with various materials to ascertain their value and utility and in the hope of eventually finding a material the cost of which, spread over a few years, would not greatly increase the cost of maintenance. Limestone and slag of various gauges dried, heated, and mixed with tar or other bituminous mixtures before consolidation and laid upon old surfaces previously scored or upon surfaces from which the old material had been excavated and removed were tried, whilst several lengths of road surface were also treated with tar in various forms. Other lengths were sprinkled with water to which had been added certain proportions of various kinds of chemicals. The results of these dust-preventing experiments were not wholly satisfactory. The tarred limestone and slag were both found to be very suitable upon roads where the traffic was more or less light, but upon roads with a very heavy traffic the tarred slag was infinitely better than the limestone, becoming too compact upon consolidation to be affected by the sucking action of motor cars. The surface, however, after slight rain was found to be somewhat slippery for horse traffic. Spraying the surface with tar was very successful but the experiments proved that the weather had a considerable bearing upon the results obtained. When perfectly dry the surface of the road was swept hard to remove all dirt and dust until the metal was exposed and the hot crude or distilled tar was poured on and well brushed in, and after being left sufficiently long to admit of the tar penetrating into the road as far as possible the surface was sprinkled or blinded with sand. When first laid and before being blinded the tar was found to lick up and adhere to the paint upon vehicles causing damage thereto, whilst during bad weather in the autumn it churned up under heavy traffic. The various chemicals and liquids tried were certainly found to be superior to ordinary water for laying dust but in no case was the success achieved of sufficient magnitude to justify a continuance of their use to any very large extent or for any length of time. The experiments, however, proved conclusively that if properly

executed under favourable conditions tarring the surface effectually and economically prevented dust, and upon open and windswept lengths preserved the surface and prolonged the life of a road. It is interesting to note that one length of road laid with tarred slag in 1905, upon one of the most heavily trafficked roads leading out of the Metropolis has never since required entire renewal. It has, however, required patching and it has been surface-tarred annually.

Although for the first few years the County Council in common with other County Councils only contributed (usually one half) towards the cost of laying dust-preventing materials on "unclaimed" main roads, nearly all the districts availed themselves of the offer, and the remainder of the cost was either borne by the Local Authorities or contributed locally. The result was that tarring the surface gradually became fairly general. A curious point, however, arose as to the legality of a District Council contributing towards the cost of tarring upon main roads in their district which were vested in the County Council, but upon being approached the Local Government Board ruled "that the contribution would be quite in order if it could be shown that the operation was of such a character as to constitute an improvement within the meaning of Section 3 of the Highways and Bridges Act, 1891."

This form of road maintenance was largely increased, with the result that it was found, in practice, that surface tarring, besides mitigating the dust nuisance, effectually prevented tracking and disintegration, whilst a great deal of watering with its accompanying ill-effects was avoided. This led to the County Council raising their contribution to two-thirds of the cost through towns and villages, where tarring was undertaken partly for the purpose of dust-laying for the convenience of the inhabitants, and paying the whole cost on open and uninhabited roads where the preservation of the surface was the primary object. Eventually the County Council decided to pay the whole cost of surface tarring, and, with the exception of those roads upon which more permanent surfacings have become imperative on account of the enormous traffic, almost the whole of the roads in the County are now treated at least once, and in many instances twice every year. The durability of the treatment varies considerably according to the situation of the road, and the extent of the traffic. Hand application is that usually employed, but various machines are now upon the market to which sprayers and brushes are attached, and these enable the tarring to be carried out much more expeditiously, which is a great advantage in our variable climate. Compounds containing ingredients other than tar are also extensively used and in some cases are more effective and durable than either crude or refined tar,

but the initial cost is, of course, higher. Granite chippings are also substituted for the sand used for blinding purposes which adds to the cost of the work. The waterproofing of the surface of roads, however, leads to a consequent reduction in the scraping and sweeping hitherto necessary, and this saving should be set off against the cost of the tarring.

Modern Methods of Construction and Maintenance.

In reviewing the latest developments introduced to meet modern traffic requirements it will be the Author's endeavour to give as briefly as possible a description of some of the well-known methods which have been adopted in Surrey and to give comparative figures of cost. It should, however, be borne in mind that the figures quoted are from actual experience when prices of materials were normal before the outbreak of the War.

Water-bound macadam.—The method of coating roads with granite, basalt, or other tough material, water-bound and surface tarred is very suitable for roads with a moderately light traffic and is that still generally adopted. The selection of the material to be used requires great care, and regard must be had to the quantity and weight of the traffic using the road. The manner in which the material is applied has been previously described, except that the early Spring is now considered the best time for carrying out the repairs. About nine yards super. is covered with a cube yard of material, and with chippings or sand used for binding, the cost works out at about 1s. 6d. per yard super. New coats should be surface-tarred as soon as the road has dried sufficiently, and another dressing given in the autumn before the break-up of the fine weather. The cost of tarring which varies according to the quality of the tar and the kind of material used for blinding purposes works out at from 1¼d. to 2d. per yard super. The covering capacity of a gallon of tar averages between 5 and 6 yards super. and one ton of grit covers from 200 to 250 yards super. The life of such a road may be generally accepted as from three to five years or more, but varies according to the traffic and other conditions prevailing. After the first year an annual tar dressing is very beneficial, the surface being thus maintained waterproof and consequently withstanding the effects of traffic and weather very much better. Until recent years the final consolidation of the metal was effected by the passage of horse-drawn iron-tyred vehicles, but this kind of traffic has of late been so materially displaced by self-propelled vehicles, which now form by far the larger percentage of the traffic, that such consolidation has become quite impossible, the material being pushed into ridges and leaving a very uneven surface at completion. Upon roads bearing heavy traffic the benefit accruing from surface tarring is comparatively small

and a more substantial waterproofing method is necessary to preserve the surface for any length of time.

Tar macadam.—On the roads with moderate traffic this material has been largely substituted for the waterbound method. Before applying this material the existing surface is scarified, formed to a proper cross-fall, and rolled. The most suitable aggregate is selected blast furnace slag, thoroughly dried, heated, and coated with distilled tar or tar compound. It is usually made in three gauges, viz., $2\frac{1}{4}$ in. (from $2\frac{1}{4}$ in. to $1\frac{1}{2}$in), $1\frac{1}{2}$ in. (from $1\frac{1}{2}$ in. to $\frac{1}{2}$ in.), and $\frac{3}{8}$ in. (from $\frac{3}{8}$ in. to $\frac{1}{8}$ in.). In two-coat work, which has a finished thickness of about 4 in. after consolidation, $2\frac{1}{4}$ in. material is used for the bottom layer and $1\frac{1}{2}$ in. for the top. Each layer is rolled separately with a roller of about 8 to 10 tons in weight, but before the top layer is thoroughly consolidated just sufficient $\frac{3}{8}$ in. material is sprinkled on the surface to fill up all the interstices and rolled so as to form a perfectly waterproof surface. The percentage of the various grades used are approximately 60 per cent. of large, 35 per cent. of medium, and 5 per cent. of fine material, but these quantities may be varied to suit the requirements. In the case of one-coat work with a finished thickness of about 3 in., material of mixed gauge graded from $2\frac{1}{4}$ in. down to $\frac{3}{4}$ in. or $\frac{1}{2}$ in. is used with a sprinkling of topping material as before. After being subjected to traffic for a month or two and when perfectly dry the surface should be dressed with tar and chippings so as to fill up all voids completely and to form a waterproof and durable wearing surface. One ton of material will surface about eight yards super., 3 in. thick, and the cost is from 3s. to 3s. 6d. per yard super., according to the cost of material and the difficulties of laying owing to the previous state of the road and amount of interruption by traffic. A tar macadam road will, with care in patching and annual surface dressings, last from five to eight years or even longer according to the amount of traffic, after which it can be re-topped or if found advisable used as a base coat for a more permanent form of bituminous surfacing. Slag tar macadam is very suitable for roads with a great deal of motor traffic. Compared with water-bound granite, the initial cost is about double, but there is a saving in the annual cost of cleaning, patching, &c., and where it is found that water-bound macadam will not last longer than three years it is undoubtedly more economical to substitute tar macadam.

Limestone tar macadam is also largely used in the same manner, but it is suitable only for roads with a light motor traffic, and where the situation is well exposed to quick-drying influences.

Granite tar macadam has also been tried with but very few satisfactory results. The aggregate does not appear to be

sufficiently porous or the surface sufficiently rough to retain the compound, the result being that under heavy traffic the material loosens and the surface becomes uneven. It does not seem practicable to keep a waterproof surface through the winter where the traffic is considerable, so it would appear to be only suitable for light traffic in exposed situations.

Pitch-grouted macadam.—This can be laid in single or double coatings according to the requirements of the traffic. In single pitch grouting the existing surface of the road is scarified and the excavated material, after being sifted to remove all stones below 1 in., is re-spread together with sufficient new granite or other suitable material of about 1½ in. gauge and rolled dry until the stone is fairly firm. The grouting mixture, consisting of pitch, oil, and sand, is then poured on to the partly-rolled surface, using as little of the mixture as possible to fill all voids to within about half an inch of the top of the stone and the surface is then lightly sprinkled with clean ¾ in. chippings. Before the grout has time to set the roller is again applied and sufficient chippings added during the process of rolling which is continued until the grout is squeezed up to the surface and becomes thoroughly cool and consolidated. After being thrown open to the traffic the surface is dressed with a further coat of pitch and oil or tar and chippings to secure a smooth and even waterproof face. Double pitch-grouting is identical except that the aggregate is laid, grouted, and rolled in two separate layers. The material for the bottom coat is of 2 in. gauge and for the top coat 1½ in. material is used. The finished thickness of single pitch grouting is about 3 in. and of double pitch-grouting from 4 in. to 4½ in. The method of preparation and finishing is exactly similar in both cases. In preparing the grouting mixture all the pitch and half the oil is first placed into a 600 gallon boiler, which is large enough to heat, safely, about 500 gallons, and is heated to a temperature of 300° Fahr., after which the remaining half of the oil is added, the mixture being thoroughly stirred during the process of heating. Clean sharp sand, heated in sand driers to a temperature of 400° Fahr., to which is added a very small percentage of Portland cement, is then mixed with an equal proportion of the pitch mixture in a dandy or portable mixing vessel, the mixture being stirred right up to the time of actual pouring upon the roadway, which is done as evenly and quickly as possible by means of ladles or pouring cans. As a rule one pound of oil is generally found sufficient for every 10 lbs. of pitch, but great care must be taken that the mixture is not too brittle, which can be remedied by adding a further small proportion (about 1 in 50) of oil. A method generally adopted of testing the pitch mixture is to draw off a little and after allowing it to cool a piece is held between the finger and thumb

of both hands and stretched until it draws out to a fine thread at least three feet long before breaking. The approximate quantity of pitch required for a consolidated thickness of 2 in., is $1\frac{1}{4}$ gallons per yard super., for $2\frac{1}{2}$ in. $1\frac{1}{2}$ gallons, for 3 in., 2 gallons, for 4 in., $3\frac{1}{4}$ gallons, and for $4\frac{1}{2}$ in., $3\frac{1}{2}$ gallons. The cost works out at between 3s. 6d. and 4s. per yard super. The great draw-back to pitch-grouted macadam is the extreme difficulty experienced in obtaining a perfectly regular distribution of the pitch mixture, any excess of quantity being followed by a tendency of the surface to corrugate and even pull in hot weather, whilst with an insufficiency of the mixture the surface is not rendered completely waterproof during the winter. For these reasons the surface seldom remains so good as well constructed tar macadam.

Wood block paving.—This is perhaps the best form of construction for roads with a great amount of traffic, particularly upon motor omnibus routes, but on account of the initial cost being high, is only at present laid upon roads of an urban character and through towns where the rateable value of the district is sufficiently high to permit of a proportion of the cost being borne by the Local Authority. Hitherto hard wood paving was most generally adopted, but of late years the use of soft wood, which wears more evenly than hard, has been very extensively increased. The deal blocks are creosoted under pressure and are laid upon a 6 to 1 Portland cement concrete foundation 6 in. to 9 in. thick floated to a smooth surface. The paving is grouted with a mixture of pitch and oil up to about half an inch from the surface and the remaining space is filled with a liquid mixture of cement and sand. The cost of this class of paving has rapidly risen during recent years from 9s. 6d. to 13s. or even more per yard super. The Local Government Board sanction loans extending over a period of 10 years for soft wood paving and 20 years for the concrete foundations, and this enables the cost to be spread by repayments of equal annual instalments of principal and interest over a long period. The useful life of wood paving may be taken to be at least 10 years and under moderate traffic may extend up to nearly 20 years. It is to be doubted, however, with the much heavier and speedier vehicles now in use, whether the life of this class of paving will be so extensive as it has been in the past. It may be instanced ,however, that Castelnau, Barnes, has been laid over 7 years, and has had no repairs to date except where trenched, although it has had a large motor omnibus traffic ever since it was laid.

Bituminous Surfacings.—The surfacing of roads with asphalte or mineral bitumen has proved very suitable for the heaviest traffic and particularly motor omnibus routes. It can either be

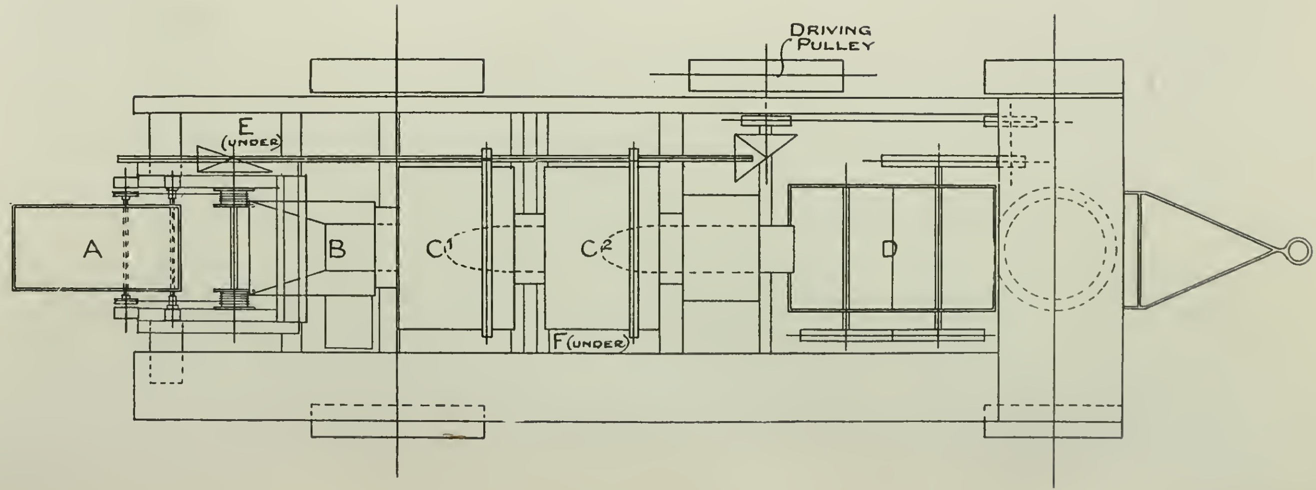
laid as a carpet coat $1\frac{1}{4}$ in. or $1\frac{1}{2}$ in. thick directly upon the existing road crust, if sufficiently strong, or upon a base or strengthening coat 2 in. to 3 in. thick of asphaltic concrete. In the latter case the carpet coat can be reduced to 1 in. in thickness. The base coat consists of about 70 per cent. of new stone or excavated road metal, and about 30 per cent. of sand and chippings thoroughly dried and heated before being mixed with hot bitumen. The carpet coat is composed of sand and bitumen, sand forming from 80 per cent. to 90 per cent. of the bulk. A small proportion of Portland cement or other suitable very fine material is used as a "filler" with the sand. The sand after being dried and heated to a temperature of about 270° Fahr., is thoroughly mixed with the bitumen heated to a similar temperature. The mixture in a hot state is spread and consolidated until a perfectly smooth and waterproof surface is obtained. Contractors manufacture and lay the material complete, or deliver the material ready for laying, but several County and Borough Councils in various parts of the country have recently had plants installed for the manufacture of this class of paving. In Surrey two plants have just recently been purchased upon the recommendation of the County Surveyor, respectively, for the manufacture of the base and carpet coats, and skeleton diagrams shewing their method of working are appended to this paper and numbered 1 to 4. The plant for the manufacture of the base coat, which is of a portable character as shewn in Plates 1 and 2, consists of a bucket elevator (A) (having a cubic capacity of half a yard) which hoists and drops the aggregate into a hopper (B) from whence it is delivered into a revolving drum (C_1) and after a certain amount of drying is passed through another revolving drum (C_2) and discharged into the mixer (D) where the bitumen after being heated in a portable boiler is added and thoroughly mixed with the aggregate by means of two revolving cranks fitted with blades. Whilst in the drums the aggregate is dried and heated, the heat being supplied from a furnace (E) and being drawn through the drums by means of a fan (F). When ready for use the material is discharged through flaps which open at the bottom of the mixer into the waiting motor lorry or cart which can be backed right under the mixer.

The plant for the surfacing material, shewn in Plates 3 and 4, is of a semi-portable character and consists of two large cylindrical revolving sand driers or drums (A) into which the sand, hoisted from the ground by means of chain and bucket elevators (B), is delivered through hoppers (C), the drums being heated from furnaces (D). After being thoroughly dried and heated the sand is again hoisted by a bucket elevator (E) into a hopper (F) which discharges into the mixer (G) where the bitumen pre-

PLATE I.

SKETCH PLAN OF GENERAL ARRANGEMENT OF DRYING AND MIXING PLANT

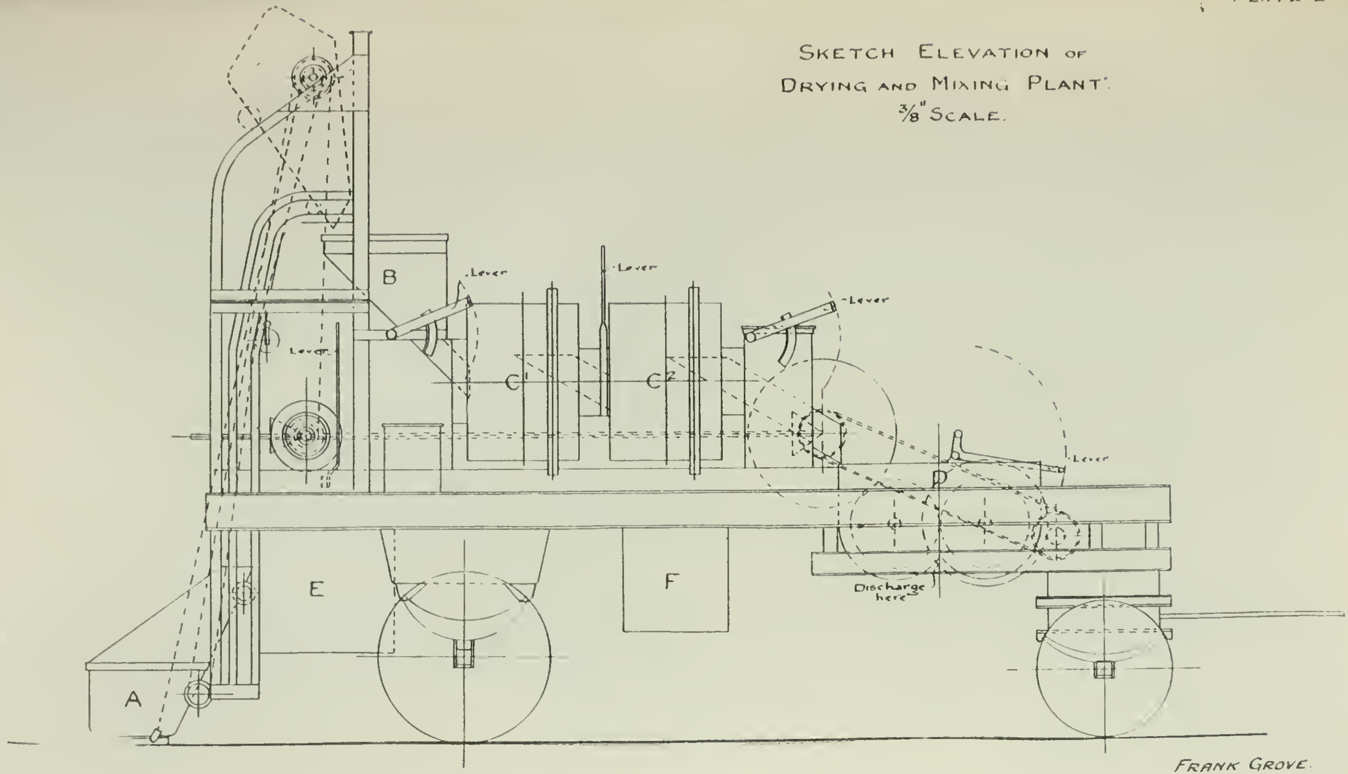
3/8" SCALE.



REFERENCE.	
A. BUCKET ELEVATOR.	D. MIXER.
B. INLET HOPPER.	E. FURNACE.
C. DRYING DRUMS.	F. FAN.

FRANK GROVE.
ASSISTANT COUNTY SURVEYOR.
SURREY.

SKETCH ELEVATION OF
DRYING AND MIXING PLANT.
3/8" SCALE.



FRANK GROVE.
ASSISTANT COUNTY SURVEYOR
SURREY.

viously heated in two tanks (H) from furnaces (J) is added by means of a travelling and tipping bucket (K). When thoroughly mixed and ready for use the material is delivered through the collapsible bottom of the mixer into motor lorries as before described. These plants having been only very recently installed it is too early to give absolutely accurate figures of cost, but it is anticipated that they will amount to approximately 1s. 6d. for the base coat and 3s. for the wearing surface per yard super. It is expected that the life of a road constructed with this class of material will be at least seven years. The covering capacity of one ton of material is as follows :—

Base coat,	2 in.	consolidated	thickness,	10	yards super.
,,	$2\frac{1}{2}$ in.	,,	,,	8	,,
Surface coat,	1 in.	,,	,,	20	,,
,,	$1\frac{1}{4}$ in.	,,	,,	17	,,
,,	$1\frac{1}{2}$ in.	,,	,,	14	,,

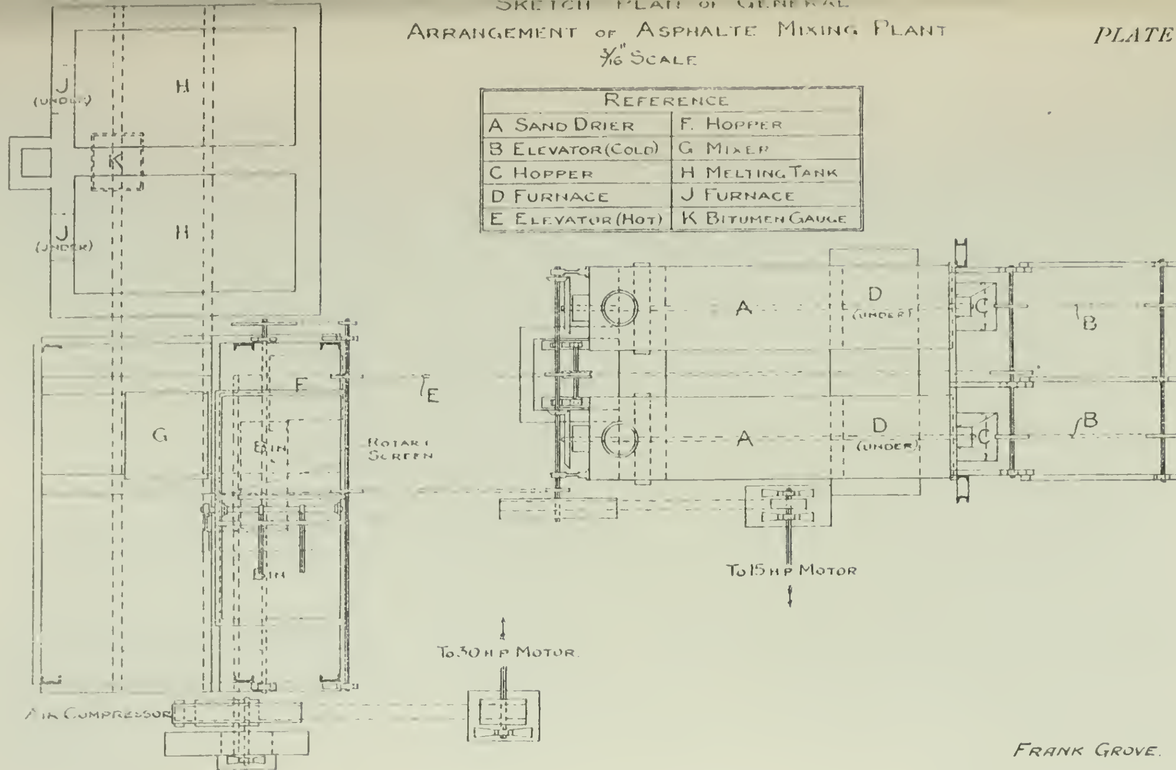
Hitherto the prices for this class of work carried out by contractors has been from 5s. 9d. per yard super. upwards.

Generally.—During the last few years every available opportunity has been taken to widen carriageways and also to reduce the camber of roads generally to about 1 in 32 with a view to encouraging, as far as possible, the distribution of the traffic evenly over the full width of the metalled surface. The reduction of camber has usually been executed by raising the sides or haunches, using large unbroken flints or other suitable material such as limestone spalls, and thus avoiding any weakening of the sub-crust of the road. Where, however, such a course has been impracticable owing to the presence of curbs the old road surface has been removed and the thickness of the new surfacing material increased. Upon rural roads, where bordered by grass margins and ditches, a considerable improvement has also been effected by the provision of continuous submerged reinforced concrete *in situ* curbs to form an abutmnt for the surfacing material and by affording lateral support to the road, effectually preventing the heavy traffic pushing the road crust into the margin. With all methods of construction where bitumen or pitch is used in a hot state there is a very great tendency to the formation of depressions or waves, which are believed to be started by the process of rolling with an ordinary steam roller in the initial stages, and a three-axle roller has been designed which is claimed to reduce the formation of these depressions or waves to a minimum.

SKETCH PLAN OF GENERAL
ARRANGEMENT OF ASPHALTE MIXING PLANT
3/16" SCALE

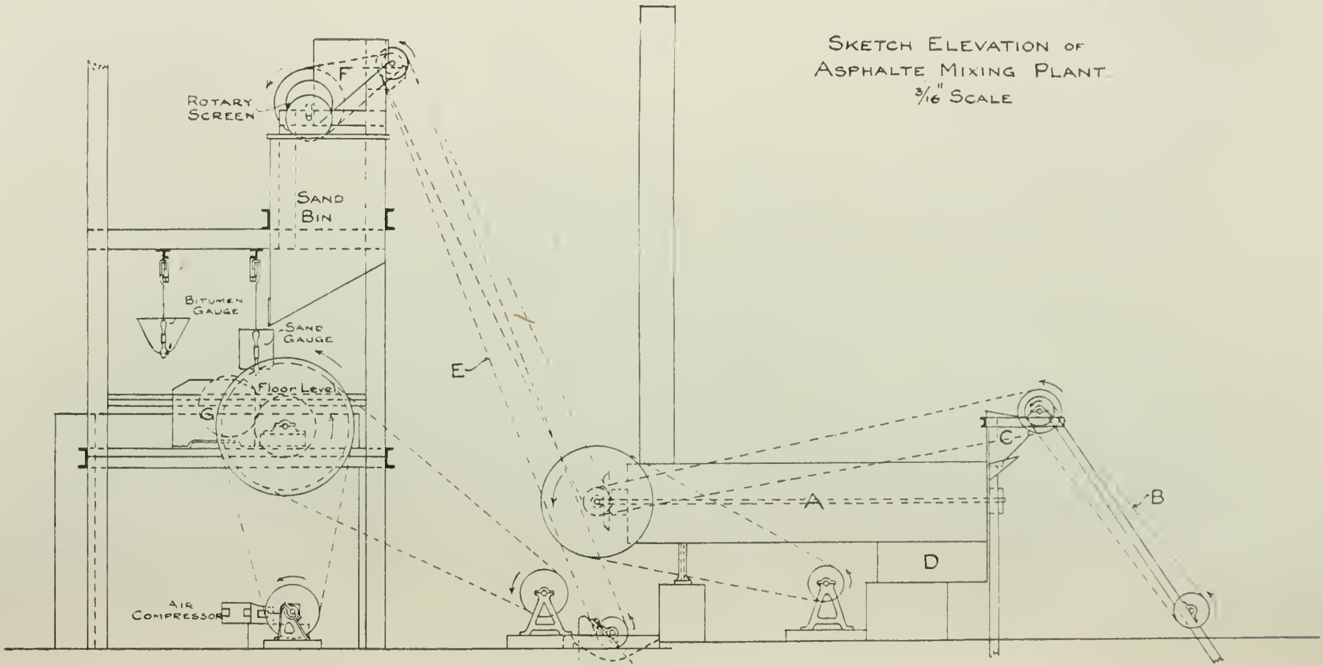
PLATE 3.

REFERENCE	
A SAND DRIER	F. HOPPER
B ELEVATOR (COLD)	G MIXER
C HOPPER	H MELTING TANK
D FURNACE	J FURNACE
E ELEVATOR (HOT)	K BITUMEN GAUGE



FRANK GROVE.
ASSISTANT COUNTY SURVEYOR.
SURREY

PLATE 4



FRANK GROVE.
ASSISTANT COUNTY SURVEYOR.
SURREY.

The Road Board.

Constituted by the Development and Road Improvement Funds Act, 1909, for the purpose of promoting the improvement of roads in the United Kingdom, the Road Board up to the present, so far as the County of Surrey is concerned, have chiefly concentrated their attention upon the improvement of road surfaces, and by way of grants out of the funds at their disposal have considerably assisted in the very marked improvement which has of late years been effected. Grants amounting to three-fourths of the difference between the improvement and ordinary costs have been made during the last four years towards various forms of improved surfacings such as asphalte, pitch, and other grouting, and tar macadams, whilst in the case of a scheme prepared last year by the County Surveyor for the reconstruction of about 26½ miles of main roads extending over a period of three years, the Board agreed to a loan free of interest and repayable in five equal annual instalments for the purchase of the necessary plant hereinbefore mentioned, and also by way of grants and free loans repayable in six years have agreed to contribute to the cost of construction, the repayment of the loans being so arranged that the cost of these roads to the county will only very slightly exceed the present cost of repairs, and will remain stationary for the period named.

The Road Board have also, from time to time, arranged with various County and Borough Councils for a number of trial lengths of roadway to be laid under the general supervision of their Advisory Engineering Committee, composed of prominent road engineers, so that the knowledge and experience gained and the results achieved by these experiments could be published and made use of by all road engineers, who have been welcomed to visit the works both during their progress and at any time afterwards.

The Engineering Department of the Road Board have also prepared for the use of Surveyors and others engaged in the work of road construction and maintenance, general directions for surface tarring, surfacing with tar macadam, pitch grouting of roads, and specifications for tars and pitch, whilst in 1911 a laboratory was inaugurated as a division of the National Physical Laboratory at Bushey Park, Teddington, where a road-testing machine was installed for comparing the efficiency of methods of construction.

Another important matter the Road Board have now under consideration is the question of preparing a detailed schedule of all the public roads in England and Wales and their division into classes according to relative importance with a view to its use in the distribution of grants and as a basis for any future

grants in aid of maintenance expenditure from the National Exchequer.

In conclusion the Author would like to express his indebtedness to the Authors of various works (including "Highways and By-ways of England," T. W. Wilkinson; and "Roads and Streets," D. K. Clark); in the preparation of that part of this Paper dealing with the history of roads; also his appreciation of the kindness of the County Surveyor in allowing him the opportunity of contributing this paper.

Discussion.

The President said that the paper which had just been read by Mr. Grove was, he was sure, of interest to many present that evening and the trouble which the author had taken in preparing it warranted him in asking the meeting to accord a most hearty vote of thanks to the author in the usual manner.

The vote was accorded by acclamation.

The President said that he had the privilege of asking Mr. Percy Boulnois to open the discussion, a gentleman well-known in the Municipal profession and one who had had considerable experience in the construction of roads as engineer at Exeter and Liverpool, and as an Engineering Inspector to the Local Government Board.

Mr. H. P. Boulnois said that he had the honour of representing the Road Board that evening, as he was a member of the Advisory Committee. He must congratulate the author upon the research which he had made in the preparation of the paper, and upon the practical knowledge of the subject which he displayed.

With regard to the condition of roads generally, and the Surrey roads mentioned on page 85, no doubt every county had suffered from the legacy of the past. Although Telford intended to put proper foundations to his roads many of them had no such foundations. Whether that was because the Turnpike Trustees were economical or not he did not know, but they must not be surprised at finding the lanes and general roads of the country without any foundation whatever. But fortunately, in many cases the metal had become so considerably consolidated that it was really unnecessary to go to the great expense of providing proper foundations, for the expense of constructing all the roads of the country on proper lines would be absolutely prohibitive.

He was glad to see that a tribute was paid in the paper to flint roads. He was speaking entirely of waterbound macadam

with which that part of the paper dealt. He had constructed many miles of flint roads, and for light traffic nothing could be better. Flint was brittle but it seemed to have some cementitious value and it formed an excellent park-like road. He agreed that it was not so strong as a granite road but, as the author pointed out, the constant flooding of a granite road, whether by artificial watering or by rain, did it a great deal of harm, whereas a flint road did not seem to suffer to the same degree. It might be that the flint road as a rule drained better than a hard water-bound macadam road. Road-makers knew that, within limits, water was as great an enemy to roads as was traffic.

The author spoke of the rapid growth in the number of motor vehicles and said that they did considerable damage to flint roads in consequence of the sucking action of the rubber tyres and so on. His own impression was that the principal damage done by motors was not by the sucking action, but by the brushing action. To give an instance, on the incline at Waterloo Station there was a long line of taxi cabs which moved only at a crawl from place to place on the incline, but the channel in which the near side of the taxis moved was worn into a deep groove. He thought that that was an absolute proof that in starting there was a brushing action of the wheels which was most disastrous to the paving, which, in that case, he believed was wood. For a long time he had had the impression that, in changing speed and in starting, the wheel rotated at a considerable speed without the vehicle progressing to a proportionate extent.

On page 89, Mr. Grove drew attention to the various machines now upon the market to which sprayers and brushes were attached, and on page 90 he seemed to speak rather favourably of tarring by hand. He would like to hear the author's view of the advantages, if any, of machine tarring as against hand tarring. His own view was that the machine had many advantages. First of all, as the author pointed out, it could do the work more expeditiously, which in this climate was most important, and secondly, the amount of tar applied could be regulated better than it could by hand. Then thirdly, if the tar was ejected by air pressure they got first of all a sort of blast of hot air preceding and accompanying the tar, which blew away the last particles of dust, and they got the tar finely atomized and driven into the road. He thought that those were points in favour of machine as against hand painting. Whether one was more costly than the other depended, of course, on how much was paid for labour.

On page 91, Mr. Grove spoke of the gritting of the road after the tar had been applied. His own impression was that in Surrey, for some reason or other, they did not approve of putting

grit or chippings on to the tarred surface. Perhaps the author would enlighten him on that point, because it appeared from the paper that grit was put on.

The paper spoke favourably of tarred slag and he must admit that he was himself a convert to it. When it was first introduced he could not believe that an artificial material like slag could ever be so hard and so useful for road making as granite, but from what he had seen all over the country, his opinion had entirely changed. It appeared that up to a certain point slag seemed to compress and become compact, and not to wear or move in the same way as tarred granite. Probably most of those present had seen quite recently in the *Sanitary Record* a controversy on the question whether it was possible to put tar on to granite so as to hold on and make a good tar macadam road.

With regard to rolling he thought that some improvement was wanted. They had now reached the stage when there should be more scientific treatment. For tar macadam roads particularly, they needed a lighter weight to start with and a heavier weight for final consolidation. Perhaps some present could design a roller that would effect that. A water ballast roller would do it, but there were little difficulties connected with it and they could not always get water. Colonel Crompton had introduced a three axle roller which he said would give a varying weight but he (the speaker) did not quite know how. In addition it was claimed that the waviness of the road, which was the trouble of all road makers, could be avoided, and the author had pointed that out.

With regard to pitch grout macadam the author did not seem to be very favourably impressed with it. There had been some failures with pitch grouting, the causes of which were too numerous to go into then, but there had been some great successes, He had in his office a sample which was too heavy to bring with him, of a pitch-grouted road which had been taken out for him at Hornsey by Mr. Lovegrove, who had mastered the subject very thoroughly. At Hornsey there were some of the best pitch-grouted roads in the country.

He quite agreed with what the author said about wood block paving. He would not say that he was one of the pioneers of hard wood-block paving, but he was a great advocate of it when it first came in, but it had failed to some extent, and principally, he thought, because it was too hard. The arrises chipped off and they got a corduroy road. The only way now in which hard wood was applied was with a sectional block, which was well known. That was a really scientific way of employing it for making a good road.

With regard to bituminous surfacing, many people believed

that what was known as the carpet system would be the road of the future, and he hoped that it would be. There was no doubt whatever, from the description given in the paper of the method of making the carpet, that engineers were trying to make artificially a "natural" rock asphalte. They were almost trying to improve on nature and make a substance which would be as near as possible to the old rock asphalte, ground into powder and laid down under compression.

He congratulated Mr. Grove on the diagrams and explanations of the plant, which must be studied at leisure. The plant for the manufacture of the base coat was said to be of a portable character. He took it that the reason why it was portable was that it was wanted close to the work, because probably the old macadam was used and they did not want to have to carry it to the depôt and back again.

With regard to submerged reinforced concrete curbs he quite agreed with Mr. Grove that it was most important that the haunches of roads should be thoroughly strong. He had, over and over again, seen failure of rural roads, due to the spreading of the haunches, which would not occur if they were made strong enough. He congratulated the author on the cost at which he was producing his carpet and base coat. If the whole could be done for 4s. 6d. per yard super. it worked out exceedingly well.

He was much obliged to Mr. Grove for what he had said about the Road Board. He honestly thought that improvement in roads had been considerably helped by the action of that Board. If it had not been for the money which the Board had granted he doubted whether any County or Borough except a very rich one could possibly have done all the work that had been done. He had seen roads all over Europe and he maintained that the roads of England were the best in the world. In Spain, where he was two years ago, the roads were too terrible for words. He had been told, and he believed it, that a week or two before he went out a mule had been drowned in one of the ruts.

On page 21 reference was made to the fact that the Road Board were considering the preparation of a detailed schedule of all the public roads in England and Wales, and their division into classes. That work had been stopped on account of the War, because the traffic on some of the roads throughout the country had been absolutely abnormal on account of the movement of troops and munitions.

Mr. H. T. Chapman (County Surveyor of Kent) supported the vote of thanks. The duties of road engineers were never more difficult than at present. Road engineers were becoming

very much like the children of Israel, because they would have to make roads with insufficient material, labour and haulage facilities. It was, at present, almost impossible to get imported material owing to the difficulties of transit, and it would be more than ever necessary to utilise local materials to their fullest extent and he thought that that could only be done by treating them with some bituminous method as was being done in Surrey by Mr. Dryland, and was adopted in Kent. He was, perhaps, more interested in the particulars respecting bituminous surfacing than in any other portion of the paper. He did not know whether Mr. Grove would agree that single coat work was of no use where the traffic was at all heavy. His experience was that unless some base coat was provided for the carpeting they were asking for trouble. He was sorry to say that many of the roads that he had to deal with were not sufficiently strong to enable the material to be scarified and treated as described in the paper, using it as a base coat, and therefore he was utilising local material, such as flint and crushed shingle treated with pitch, and surfacing that with a bituminous carpeting. There had been failures in almost every description of road treatment ever since he could remember and long before, but he thought that they were now working on right lines. He did not quite agree with the author and Mr. Boulnois that the waviness or corrugation referred to was in all cases due in the inception to the rolling. He thought that it would occur from the motor bus and heavy quick traffic of the present day, however good the surface was at first. No doubt, it would be very greatly reduced by more scientific methods of rolling and he quite agreed that rolling from the side to the centre to commence with was the best method that could be adopted at the present time, and was better than beginning to roll the roads longitudinally. Granite set paving had not been mentioned to any extent in the paper. They all realised that on the ordinary rural road they could not afford it at present but there was no doubt that in regard to many roads of which he had experience in Lancashire and in the neighbourhood of large county boroughs it had been the most economical form of pavement.

Mr. Grove mentioned the use of Portland cement as a filler. He thought that he would agree that there was no cementitious value required and that it was simply used to make a particularly dense mixture. He himself had used pulverised clay, ground practically as fine as Portland cement, with equally good results at about half the cost. Also in pitch grouting, instead of using sand, he had used the same filler of a very low specific gravity, and had found that the result was that a very much larger area could be treated with the same weight of material, and that there had not been softening owing to high temperatures in the summer.

Mr. Wilkinson (Deputy Borough Engineer, Wimbledon) said that his chief, Mr. Cooper, regretted that, through illness, he was unable to be present. Flint roads in Wimbledon, after being tarred, had stood better during the winter months than any of the macadam roads, and he thought that that was due solely to the thicker coat of tar that could be put on and sank further in. They were " blinded " with pea gravel.

With regard to the brushing action of motor-car wheels, they laid asphalte last summer on an important road, where he had watched the motor cars and buses going over it, and agreed with Mr. Boulnois that it was solely the brushing action which began the corrugations in the road, which were deepest where the motor vehicles started and stopped. These corrugations continued to grow in length and depth.

From his observations on machine versus hand spreading, he concluded that machine spreading was superior to hand spreading, although his chief was a confirmed believer in hand-spread tar.

If engineers paid more attention to tar macadam it would come out much better than many of the asphalte or bituminous roads that had been laid. He had come to that opinion only during the last six months, but he firmly believed that the tar macadam (slag) road was the road of the future.

With regard to rolling, he did not know whether the last speaker intended the cross rolling to be done with a heavy hand roller, or by a light mechanical roller. He thought that if a heavy hand roller was being used it was preferable to cross roll before using the heavy roller. Mr. Cooper had tried during last summer putting down a large steel plate in front of the roller, but observations had not been extended far enough to enable them to know the amount of corrugations that would appear. There were corrugations even with that.

Mr. Boulnois said that he did not follow how the steel plate was used.

Mr. Wilkinson said that the steel plate was 8 to 9 feet square. It was laid in front of the roller, and the roller changed direction solely on it. The idea was that in changing direction the weight rested there twice as long as on any other part. As they were aware, rollers changed direction very slowly.

The President asked whether there was another plate at the other end of the space where the change took place.

Mr. Wilkinson said that the plate was moved from one end to the other across the road only as the roller changed direction on the hard material at the other end of the portion to be rolled.

Of course only short lengths were rolled at a time. The road was asphalte. He had not had experience of a three-axle roller. He had been over some roads that had been rolled by it, but they seemed to be quite as wavy as with the ordinary roller.

He was sorry that the paper did not say anything about reinforced concrete foundations. His opinion was that a good foundation was everything. He had not had any experience of reinforced concrete foundations, but he would like to know whether the author had, and what conclusions he had come to.

Mr. W. H. Grieves said that as to flint roads, he agreed with Mr. Boulnois that they were really excellent roads for light traffic. especially as they could be tarred over every summer. He did not know a road that took the tar better than a flint road, or where there was better penetration. Recently he had taken up some surfaces in which, after two years, the penetration appeared to be at least two inches. The tar had been spread with a tar-spraying machine, which he preferred to hand painting. The latter could really be done a little more cheaply ; he supposed that the figures were 1d. or slightly more for hand painting, as against $1\frac{4}{5}$d. or $1\frac{3}{4}$d. for tar spraying by machinery. That included everything, the clearing of the road, the tarring, and the gritting.

He agreed with the author that wood paving was excellent, but he did not agree that the amount of concrete mentioned as the minimum should be laid in these days. He had heard of cases where wood paving had been laid on concrete 6 or 7 inches thick, but the action of severe motor traffic had crumbled up the concrete underneath the wood, and a very substantial thickness of concrete was therefore required for wood paving. At any rate, it ought not to be less than 7 inches, and wherever motor traffic was likely to go over a road the concrete should not be less than 9 inches thick.

As to corrugations, they did not occur only on roads used by motor buses. There had been corrugations on roads ever since he could remember anything about roads. They appeared on the old-fashioned macadamised roads, but engineers did not take very much notice of them then. He did not think that they were altogether formed by the traffic. The action of rain and wet had a good deal more to do with them than was generally supposed. In severe rain storms like those of the previous winter little rivulets were formed which flowed from the centre of the road to the sides, and in those places a good many of the corrugations appeared. The problem of dealing with waviness, especially on bituminous roads, was a very intricate one, but he had no hesitation in saying that even the waves of bituminous roads would be overcome by and by.

Mr. William Menzies (Egham) called attention to the passage on page 87 that spoke of the damage done by breaking up roads for sewers, and for gas, water, and other mains. One of the most trying things that road surveyors had to put up with was the horrible state in which trenches were left by the companies that opened the roads. He ventured to suggest that the Road Board or some such high authority should, as soon as circumstances would allow, introduce, if they had not already done so by means of legislation, powers by which the companies who now destroyed the roads at their will, and snapped their fingers at surveyors, could be forced to do something towards restoring the surfaces to the *status quo ante.*

With regard to watering tarred roads, he found that in an urban district the watering was very little reduced, if at all, from what it was before tar was put on the roads. Horse droppings dried at a very rapid rate, and they were swept and swished about on to the pavements and into shops, and created a great deal of trouble and annoyance to passers-by and to residents. His water cart was rather more sought after now than it was in years gone by. Everything that fell on to the surface of roads dried so rapidly that it was very soon converted into dust and dirt and distributed on the paths and in shops.

On page 92 Mr. Grove said, " After being subjected to traffic for a month or two and when perfectly dry the surface should be dressed with tar and chippings." Why wait for a month? He had generally found that it was better to do the work as soon as possible after the tar macadam had been laid than to give the traffic a chance of wearing the tar off the surface of the newly laid material before they could put the finishing coat of tar and chippings on it.

On page 94 Mr. Grove, speaking of wood block paving, said: " This is, perhaps, the best form of construction for roads with a great amount of traffic, particularly upon motor omnibus routes." He (the speaker) did not see any mention of pitching, meaning by that granite cubes. He could not help thinking that one of the roads of the future would be a granite set road. The old objections that were raised to that were, he believed, mainly two. One was that it was very noisy on account of horses' shoes and iron-wheeled traffic, and the other was that it became very slippery. With regard to slipperiness, where tar macadam or asphalted roads had been introduced, they had a condition of things as bad or even worse than where granite cubes were used. He thought that the noise would almost entirely disappear, because horse traffic was rapidly going out of existence and there would be no noise from motor traffic. The granite cubes would rather have the effect of wearing away

the motor wheels than of the motor traffic wearing away the granite cubes. The expense would no doubt be very great; but he thought that the lasting quality of the work would largely compensate for it.

Mr. Percy Griffith said that the last speaker had not been over-complimentary to the authorities who had the responsibility for maintaining pipes, supplying gas, water, electricity, and the like. He wished to assure Mr. Menzies that these authorities did not open the roads for fun. The work was costly, and was not undertaken without serious necessity and in the interests of the community, for it must be remembered that leakage had to be paid for by the consumer, and thus the community ultimately benefited by its prevention.

The question of the repair of trenches was a difficult one, and if road authorities could provide subways for pipes, the authorities concerned would use them with pleasure; but while they had to lay pipes in the virgin soil and open the road to obtain access to them there would be a difficulty in maintaining the road surface. He would like to ask Mr. Menzies whether, in repairing sewer trenches, he did not find the same difficulty, and whether the users of the roads were always content with his work. It was also becoming a very general practice for gas and water companies to leave the actual repair of the roads in the hands of the surveyor, paying for the cost of the work, and in that case the surveyor could not grumble at the result; but, even then, he thought that the users of the roads might occasionally complain about the state of the trenches. The repair of the road surface over a trench was, as a matter of fact, not an easy matter, and, although every precaution might be taken, trouble would often arise owing to circumstances beyond the control of those who made or repaired the trench. Parliament was particularly exigent at the present time with regard to the matter, and he thought that while there might be exceptions, it was hardly fair that water and gas authorities, generally should be charged with neglect of the public interest. After all, the pipes laid under the roads were as necessary to the community as the roads themselves.

Mr. Ware (Epsom) said that he had spent the whole of his professional life in Surrey on some of the roads that had been referred to that evening.

Mr. Griffith was evidently interested in water and gas. As had been said, the great destroyer of a well-made road was the badly filled trench of the gas or water company; that statement did not apply to electric light companies, because in the case of those companies local authorities had certain powers

with regard to reinstating the trench from the bottom. If exactly the same power were obtained with regard to water and gas trenches and even sewer trenches (because the highway official was not always the Public Health official) he was quite sure that there would be no difficulty whatever in making good roads that had been damaged. He had repaired many miles of electric light trenches, and even after twelve months there had been no trouble with them. Gas and water trenches were constantly sinking, and sewer trenches sank even twenty years after the sewer was laid.

With regard to tarring, for fourteen years he had followed the method of tarring roads by hand. He thought that Surrey was the first county to adopt the system of tarring to preserve the roads and prevent dust. He was a firm believer in the tar brush; but there was now difficulty with regard to labour. To work the tar brush properly, a certain number of men were required, and as these extra men could not be had now, he was reduced to the use of a machine. He did not quite agree with Mr. Boulnois that tar projected on to the road by pressure was of any use at all. The most effective tarring of roads was where the tar spread in a certain thickness was allowed to sink in by capillary attraction. He usually allowed a gallon to 4 or 5 yards super. In that way the best results were obtained. Some of the roads in his district had not, for years, been repaired nor wholly tarred every year, but had only been patched with tar in places. The surface of these roads was level as a billiard table, and did not show corrugations. The situation was on the chalk, and the traffic was chiefly fast-moving light motor traffic. The machine that he had, distributed the tar on the road and afterwards brushed it in mechanically. He believed that that was the nearest to hand work that could be got, and that hand work was the best method.

He would like to know how to prevent corrugations. He agreed with Mr. Chapman that all corrugations were certainly not due to rolling, although in some cases they might be started by rolling. Very severe corrugations were found on roads which had never had a roller on them. The roads in Surrey which he had to maintain had no foundation whatever and were liable to spread under the heavy traffic. On some of the roads hips of reinforced concrete had, on the instruction of the County Surveyor, been put in, and what had been done had proved beneficial, as the reinforced curbs had stopped the spreading of the road and had helped to maintain the centre in fairly decent order.

Mr. E. H. Collcutt said that the gentleman who had so ably championed the cause of the gas and water companies had mentioned that in many cases the work was left in the hands of

the road authorities. Did he refer to the reinstatement of the surface alone or to the actual filling of the trench? The difficulty seemed to be with regard to the latter and the repair of the surface was a comparatively simple matter, if the subsidence due to bad consolidation lower down could be avoided.

Mr. Griffith was understood to reply that he referred to the repair of the surface only.

The President said that he thought that the point in the discussion which had the most fire in it was what Mr. Griffith had said with regard to gas and water trenches. He could not agree that the difficulty arose from badly filled-in trenches. Everyone would realise, and no one more so than those who had the charge of roads, that, however well a trench was filled in, and however careful an engineer might be to reinstate the disturbed surface in a proper manner, it was impossible to get the road into the condition it was before the opening was made, and that was the whole trouble. For instance, if a coat was torn, no tailor could ever repair it so that it was in the same condition as before it was torn. What engineers complained of more than of anything else was that those who had power to open the highways would not take the opportunity of making their openings before the road was finished. Very often the companies had notice that work was going on, and they would not take the opportunity of doing their work; but as soon as the road was completed, they insisted on repacking or rejointing a main or putting a slot meter connection to a house, and the whole trouble arose from that. He could corroborate what Mr. Boulnois had said about the condition of roads in England. Road engineers were to be congratulated on the fact that there were no highways comparable with those roads. He had travelled over very nearly 3,000 miles of highway in Belgium, Germany, Austria, and France; but in no case had he found any highways, as a whole, equal to those of this country. There was a want of attention to French roads. They seemed to be repaired and then entirely neglected until repair again became urgent. He could not agree with the author with regard to patching. The best Continental roads that he had come across were in Austria where they had systematic darning of roads, not patching; but the old darning roadman seemed to have disappeared from this country. They could not get a man to marry new work to old in a nice manner.

Mr. Boulnois had referred to Mr. Lovegrove of Hornsey. He (the President) had inspected many of Mr. Lovegrove's roads; but he thought that he had left his old love—pitch grout—and gone to bitumen. All the roads that he was carrying out now had a bitumen carpet.

With regard to the watering of roads after tar spraying, he thought that Mr. Menzies had clearly demonstrated that it was not water that was wanted on roads after they had been tarred, but really more attention to scavenging.

He would give a word of warning to those engineers who were inclined to adopt the practice mentioned on page 95 of the paper of using excavated road material in the preparation of the bottom coat of the bituminous road. The use of old material with new had the result that, however carefully the old material was screened, there was undoubtedly a slight film of uncementitious material adhering to the old stones. It was a very doubtful point whether, with that slight film of dirt, they would get the bitumen to adhere to the granite to such an extent as to make a solid mass after rolling. He had used old granite with ballast in connection with the making of concrete, and he had found that the uncementitious film was very detrimental to the concrete, and he had given up the use of it. He had not used old material himself ; but he would advise engineers to be careful as to its use, or probably the life of the road would be so shortened that, instead of a slight decrease of cost being obtained, the cost might be increased in the future.

Reply.

Mr. Frank Grove, in reply, thanked the meeting for the vote of thanks which had been accorded to him, and said that he appreciated very much the honour of reading a paper before the Society. He also very much appreciated the presence of a gentleman with such a wide knowledge of road construction as Mr. Percy Boulnois, to open the discussion.

With regard to the points raised during the discussion, he was entirely in agreement with Mr. Boulnois regarding flint roads ; but with regard to the wear of the wood paving in Waterloo Station he would suggest that that was probably due to the drivers putting on the brakes so quickly that the wheels skidded.

There was a great deal of diverse opinion with regard to tarring by hand and tarring by machine ; but, as had been pointed out by Mr. Ware, the results which had been achieved by Mr. Ware in his district for a number of years past had been better than in a good many other districts where the machine had been used. Mr. Ware, at any rate, seemed to be able to get the tar well into the roads, so much so that it was not necessary, after the first year, to give them a thorough resurfacing.

Mr. Boulnois had mentioned that he was under the impression that tarring in Surrey was not blinded. He (the speaker) knew of no case where no blinding material was used in Surrey. Were such to be the case the engineers would be inundated with

complaints from motorists and others using the roads. He ought, perhaps, to have mentioned in his paper that the carpet coating was rolled by hand rolling with a heavy roller across the road before the steam roller was applied. As to the rolling of tar macadam, a six or an eight ton roller was used in the first instance, wherever it was possible to obtain one, before the ten ton roller was put upon the road.

With regard to what Mr. Chapman had said, in Surrey they were suffering from inability to obtain material for the repair of roads ; in fact the only materials that they could get were those for which the War Office had placed trucks at their disposal to keep in something like passable condition the roads which War Office traffic had severely damaged. He entirely agreed that single-coat work except under very favourable circumstances was not so successful as two-coat work. He had mentioned in the paper that waves were believed to be caused by rolling in the initial stages ; but he did not know whether they were or not.

He had purposely omitted to mention granite set paving because in Surrey they had only a very short length of road constructed with that material.

As to the use of Portland cement as a filler, they had found other suitable fine material, as he stated in his paper. They used what was called a grey filler, which it was thought would prove equally as good as Portland cement, and nothing like so expensive.

The question of the reinstatement of trenches was rather a knotty one. His opinion was that if the District Council took over the trench directly the pipe was laid and saw to the filling and ramming right from the start, they would do their best to make a much better job of the work than contractors' men or men from gas or water companies. It was not of much use for the District Council to give companies a price for reinstating the surface, if they had not seen to the proper ramming of the trench at the bottom. Surrey was going to fight a bill in Parliament this session in an endeavour to get a clause inserted in the Bill which would enable them to take over the trench from the time of the pipe being laid.

With regard to the watering of tarred roads, in Surrey they would much rather that the water cart was kept off the roads.

As to leaving the road for a month before tarring was carried out, invariably when the roller left the road the tar macadam was not quite consolidated, and it was necessary for the traffic to consolidate the material thoroughly before it was in an absolutely fit state for tarring. He had tried to make the paper interesting, not only to road engineers but to other members of the engineering profession, and also to laymen, and he hoped he had succeeded.

May 11th, 1915.

NORMAN SCORGIE, M.Inst.C.E., President, in the Chair.

SOME FUTURE DEVELOPMENTS IN HEATING AND VENTILATION.

By A. H. Barker, B.A., B.Sc., Wh.Sc.

It is somewhat surprising, in view of the immense importance to mankind of the twin sciences of Heating and Ventilation, that the amount of attention hitherto paid to the scientific aspects of these subjects, both on the part of the scientific man and of the engineer, should have been so small. The subject, indeed, is hardly seriously regarded as capable of scientific treatment by the average engineer, who probably looks on it as a branch of plumbing or building, calling for a certain knowledge of rule of thumb and a certain amount of practical experience, but at the same time hardly a fit subject for the scientific engineer. Although the science of this subject is yet in its infancy, the author is anxious to secure a more just recognition of its position as a serious branch of engineering, and takes this opportunity to explain to his brother engineers how and why this view is a totally erroneous one, and to discuss the general nature of some of the problems yet unsolved. It may safely be said that there are more unexplored problems of science and greater difficulties attending their solution in the case of heating and ventilating than in almost any other branch of the profession, and the author has had some experience of a good many. In Germany, that uninspired land of detail, where the minutiæ of the subject have been thrashed out with a meticulous care which seems to us to be almost absurd, the real essence has been entirely missed.

This erroneous view of the science as a mere matter of rule of thumb has been fostered in the past by the extremely unscientific manner in which the subject has been treated by writers of technical books in America and England. Any educated engineer studying some of this literature must be driven to the conclusion that there is really no science whatever in the subject.

The reasons why it has failed hitherto to come up to the standard attained in other branches of engineering are not difficult to understand. They are the immense complexity of the factors which go to make up any given result, the difficulty of defining in terms of exact science what that result is or should

be, the fact that the criterion of success up to the present has, of necessity, been the feelings of individuals rather than the readings of scientific instruments. Added to these is the immense power of adaptability of the human organism to varying conditions, which tends to make actual variations of conditions appear unimportant in practice. The circumstance which differentiates this branch of engineering from almost all others and at the same time introduces difficulties unknown in all other branches is that we have here to take account of the variable human factor, both as to its physiology and its pyschology, as an essential part of the problem. In this sense we trench on the domain of the physiologist and hygienist to a degree unknown in any other branch.

It is easy to understand that this combination of difficulties tempts the busy practical man to be satisfied with any sort of result, and to leave to Nature the task of adapting the organism of the sufferer to the conditions produced by the engineer—a task which she can often accomplish, but often not without injury to the individual. The present lack of exact knowledge makes it difficult or impossible to hold the practical man to any precise standard of accomplishment. In other words the practical man can get along somehow, with a very small modicum of knowledge. It is the general attempt to do so which has led to the undoubted state of discredit in which this branch finds itself to-day.

All engineering is merely glorified common sense. The training of an engineer leads him to try to deal in a common sense way with objective facts as he finds them. In this branch the first obstacle is the great difficulty of finding what are the facts.

Consider for instance the first problem which would meet a scientific engineer endeavouring, without previous experience, to arrange a satisfactory scheme of ventilation for a building. He would commence with the assumption that the artificial ventilation of a building consists in forcing in a calculated volume of air, a task which, if he were familiar with fans and the laws of the flow of air in ducts, he might think he could easily accomplish. After he had made one attempt to satisfy the occupants of the building by proceeding on the assumption that this is the only requirement, he would find out that one essential factor in the problem was to study the distribution of the air currents in the building itself.

Even in a small building, this is in itself a problem of very great difficulty. Although each one of these currents obeys laws of nature as rigidly accurate as any other laws of nature, yet the number of influences having an effect on the air currents is so enormous that the complexity of the result is almost

immeasurable. In the attempt to lay down in terms of exact science the laws which govern this result, any person might well be baffled and unable to trace with any clearness the operations of any law at all. The reason is, of course, not that the law is not there, but that it is so complex that it would take almost a superhuman intellect to analyse it completely.

Further, who can say what system of air currents in a room —say a theatre—is to be aimed at? We all know that complaints of the ventilation of almost every public room are universal. Yet there is no general agreement, either what is wrong or what is needed to put it right. How is it possible to hold the ventilating engineer responsible for a poor result when no one can specify what the result ought to be?

I have made reference to the complexity of only one of the constituents of ventilation. Those of heating are no less complex. We have two totally distinct forms in which heat is delivered into the room, namely, convection currents of heated air and radiant energy. These are as distinct from one another as light is distinct from sound. Yet, up to the present, no formal recognition of their entire separation from one another has been recognised in current literature. The cause for this is easily seen to be that, different as these two forms of what for convenience we call heat are from one another, yet they can be instantaneously transformed from one to the other and back again. Their measurement, again, is not a problem to be easily solved. No sooner does one measure the amount of radiant energy than the mere act of measuring it turns it, or part of it, into convected heat.

The difficulty, however, which is the most baffling in the attempt to reduce this subject to an ordered science is the fact that the object of both heating and ventilation though primarily physiological, is also to some extent psychological. The primary object is to keep the inhabited rooms healthy; of almost equal importance is the necessity to keep them comfortable. The effect of any given condition on the human body is, if possible, more complicated than the laws which govern air currents and heat flow. The physiologist cannot yet tell us in exact terms what are healthy conditions for inhabited rooms. He can give us generalities only, and the experiments on which even these generalities are based are far from convincing. He cannot even, for instance, tell us what is a healthy temperature for human beings to live in, nor does he seem to realise that when he speaks of "the temperature of a room" he means merely the temperature of a thermometer suspended in the room.

Some physiologists say (and the author agrees) it is desirable in the interests of health that the temperature maintained should

be as low as a human being can endure without real discomfort. Yet others will say this is nonsense, that the room should be so warm that the man feels comfortable without any effort. Neither can anyone tell us within 300 per cent. how much fresh air per head per hour is the minimum consistent with health. Indeed, as a fact, such a crude statement would have no meaning in the real science of the subject. It depends on the temperature, humidity, and a score of other things. Physiologists cannot agree as to the chemical nature of healthy and unhealthy air. Books on the subject of climate do not give any explanation of what physical conditions constitute a bracing or a relaxing climate. Indeed most of the hygienists do not seem to realise that such words need any further description.

The matter is yet more complicated when we consider that one object the heating engineer has in view is to make persons comfortable. We here come across the baffling fact that a man is comfortable when he thinks he is comfortable. If we can make him imagine he is comfortable without the alteration of any single condition, we can make him feel comfortable. Make a man imagine he is cold or feels a draught, and he will at once want to shut all the windows. Convince him on the other hand that to shut the windows is unhealthy and stuffy, and the same man will not be comfortable unless the windows are open. One can train oneself to feel comfortable in anything.

In further illustration the author will refer to a psychological experiment he made on a medical man who was a guest at his house some years ago.

We were sitting in a room which had a thermometer suspended on the wall. The visitor made some remark about a "shoemaker's wife" and complained of the room being cold. It was freezing outside: the thermometer on the wall read 54 deg., and was a correct one. The author's view is that such a thermometer reading is quite consistent with health and comfort, when it is freezing outside. We fell to a discussion of temperatures, and it was suggested, as an experiment, that the temperature of the room should be gradually raised until the guest felt comfortable, to ascertain whether he found a temperature of 60 deg. too high. The room was provided with a fairly powerful heating apparatus. The author went into the cellar, pretended to stoke up the boilers and to turn the radiator full on. As a fact, nothing was done either to the boiler or the radiator, though the doctor was allowed to hear the clattering of the fire-doors and fire-irons. After a short interval the thermometer was changed unobserved by the visitor, for another precisely similar in appearance which read 6 deg. too high. When it had been placed on the hook without his seeing the change, it was shown to him, and he was asked whether that temperature made him more com-

fortable. He said the temperature was then just right for him, neither too hot nor too cold, although the real thermometer reading was precisely the same as it had been in the earlier part of the evening. That little experiment is most illuminating as showing the extraordinary difficulties attending an attempt to treat this subject scientifically.

It is an undeniable fact that a room filled with air which, so far as chemical analysis can detect, is absolutely pure may *feel* very stuffy. For instance, the House of Commons, on the ventilation of which the author has experimented for many months for the Committee of the House, the air in the debating Chamber is, chemically speaking, as pure as in any room in the world. Fresh air simply pours into it in extravagant volumes. In a moderately full house there are no less than 13,000 cubic feet of air supplied per head per hour. Yet it produces, without any possible doubt, the effects which we are accustomed to think of as associated with defective ventilation—lassitude, sleepiness, infection and so forth. Complaints are loud and quite general.

A room may, on the contrary, feel fresh and sweet in which, judged by chemical standards, the air is very bad. The author has analysed air containing 25 volumes per 10,000 of CO_2. which felt as fresh as a Spring morning, although 10 volumes is regarded as the extreme allowable impurity in current science. There must be some combination of chemical or physical conditions which accounts for the effect so far as it is objective—when it is purely subjective, of course, it is impossible to analyse the effect. Nobody up to the present has ventured to specify what is that combination.

Now the future of the sciences of heating and ventilation depends, on the scientific side on the further analysis of the conditions which produce the feeling of comfort and other effects. On the practical side they consist of the application of those discoveries so as to bring under control each of the conditions, and on the further developments of economy of construction and transmission and the better control of the forces we bring into play. Before we can get a step further we must be able to express, in exact terms, each of the chemical and physical conditions which go to make up the sum total of the room condition.

The criterion of our success, as I have said, is, and must be the effect on the feelings of an individual. But, we must, in order to give this subject a scientific basis, be able to translate the feelings of an individual into terms of measurable physical conditions, and this is our first difficulty. We may lay down certain physical conditions which we conceive to be necessary to the production of comfort and health, and we may direct all our attention towards producing those conditions. We may

succeed completely in doing so, and find that when we have done it that some individuals will find that those conditions are not such as are necessary for their personal comfort. We may then get other bases to work upon and still find that the new bases themselves are not any more suitable than the first.

It is clear that the only legitimate function of the engineer as such, is to produce and control certain specified conditions. The criterion of his success must not be the self-contradictory feelings of the occupants of a building, but they must be the exact readings of well-defined measuring instruments, such as radiometers, hygrometers, air meters of various kinds, apparatus for the analysis of air, dust counters, thermometers and other instruments.

The other half of the problem is for the physiologist and the hygienist, viz.: to specify what are the conditions which will be regarded as healthy and comfortable. It involves essentially experiments on human beings, which are in their very nature, illusory and extremely difficult. In essence they are, in reality, so many attempts to calibrate human beings. The science of the subject is only in its infancy as yet. The instruments brought for your inspection to-night have been designed mostly by the author in an effort to arrive at a clearer basis for analysing these problems, for future developments depend on this analysis to no small extent.

Let us consider first the problems of heating stated in general terms. The practical problem before the engineer is to introduce heat into a building in such quantity and in such form as to make the building comfortable. It will be evident that as heat can be introduced in two different forms, namely by convection currents and by radiation, there will be at least two corresponding conditions as to temperature in a room which must be observed by the heating engineer. The very existence of these two conditions has received no recognition in any of the classical literature on the subject. Indeed, as has been previously remarked, it does not seem generally to be clearly understood what is the meaning of the expression "temperature of a room."

This expression is commonly understood to mean the reading of a correct thermometer suspended in the room. Now a thermometer suspended in a room does not indicate the temperature of the air surrounding it. It is also largely influenced by the amount of radiant energy impinging on the bulb, which has no connection with the air temperature. For instance, one sees in the Winter time the caretaker of the tools used in road-mending operations seated in a sentry box before a coke fire quite comfortably, although the air surrounding the fire on all sides is sometimes far below freezing point. A thermometer suspended near the fire will obviously read fairly high, although the

temperature of the air surrounding it on all hands may be far below freezing point. It is well known that the radiation passes through the air without warming it. This is an extreme example of this phenomenon, but it brings clearly into prominence the fact that a thermometer indicates its own temperature only, when it is hung up in a room. It clearly does not necessarily indicate the temperature of the surrounding air, neither does the reading of a thermometer form any reliable guide to the feeling of cold or warmth in a room or out-of-doors. The problem has been treated in the past as though all that was necessary was to introduce heat in any form sufficient in quantity to cause a thermometer suspended in the room to read a certain figure say 60° or 65° F. There is no problem at all in that—anybody can do it. One can procure a radiator of suitable size, which is easy enough to calculate, and a suitable boiler, connect up with piping and there you are! It is true that there is a very great deal of calculation involved in so designing a large system of pipes that the flow to all parts of the apparatus shall be uniform and proportional. But even when this is done there is undoubtedly a great and increasing number of persons who say they cannot endure what they call "apparatus heat" in any shape. They cannot say why—and very few people can tell them why. Theories that the heat is a "dry heat" are absurd. Radiator heat is no more dry than any other form of heat. The heating engineer says: "there is your thermometer reading 60°—a beautiful moderate temperature—what more do you want?" The man says, in effect, "I do not know what I do want but I do *not* want to be stifled and I do *not* want to be cold. Can you not give me heat which keeps me warm without choking me?"

Now, that is a very real problem of which we must get to the bottom. Why is it that radiator heat is so distasteful to many persons? How far do imagination or psychological influences account for it? Obviously a careful analysis of room conditions must involve an investigation of all these matters.

It is evident that the first thing which should be analysed in the endeavour to arrive at the actual temperature conditions of a room is both what is the temperature of the air itself and what is the temperature corresponding to the radiant condition. The author has introduced a conception which he has named the "radiant temperature." The idea of it is the temperature which a thermometer would register if there were no air in the room at all, a sort of mean of the temperature of the surrounding walls.

As an illustration, consider the following: In an ice cave in a glacier in Switzerland, on a very hot day, the radiant temperature in the cave was (obviously) 32° F., but the air tempera-

ture near the mouth of the cave exceeded 70° F., yet a thermometer at this point read 56°.

Or again, conceive a room heated on a cold day by blowing hot air into it. Here it is evident that the hot air is the sole source of all the heat supplied to the cold walls. The air must therefore be hotter than the walls. The radiant temperature must be lower than that of the air.

On the other hand, when a man keeps warm while sitting in the cold open air in front of a coke fire devil, the radiant temperature must be higher than that of the air.

What is the nature of the physical effect of these two different conditions on the human body, and what is the effect on the sensations? Please note that the physical effect is a different thing from the sensations produced. It is necessary to investigate both. How far does the difference account for the complaints we hear of the stuffiness of radiator heat or of the lassitude produced by the plenum system. How far is either related to the rate of heat loss from the body of a human being? Does that rate of heat loss absolutely condition the degree of comfort experienced? If not, what other effect is there?

To make a systematic beginning of unravelling this tangle of questions we must first develop experimental means for recognising and measuring the four different quantities, air temperature, radiant temperature, quantity of convected heat, and quantity of radiant energy.

Even before this is done it is necessary to determine experimentally what is the relation between the thermometer reading, the air temperature, and the radiant temperature. An extended investigation on this point has been made at the University College. We have also devised two instruments for separating the air temperature and the radiant temperature. These instruments are now on the table. They are far from being ideal instruments for the purpose, as they are both expensive and difficult and very tedious to manipulate. Something of a much simpler character will be necessary before we can say that this problem has been satisfactorily solved in a practical manner.

The principle of these instruments is comparatively simple. Essentially they are modifications of the same instrument.

The first (fig. 1) has as its object to ascertain what is the mean temperature of the surfaces of the walls of the room and of the furniture and of all the exposed surfaces the temperature of which have an effect on the bulb of the thermometer. The principle of the instrument is to surround a delicate thermometer with air at the same temperature as that of the room, and also to envelope it on every side with a surface whose temperature can be adjusted to any degree and to an absolute degree of uniformity. This is secured by making a double walled vessel, filled with water

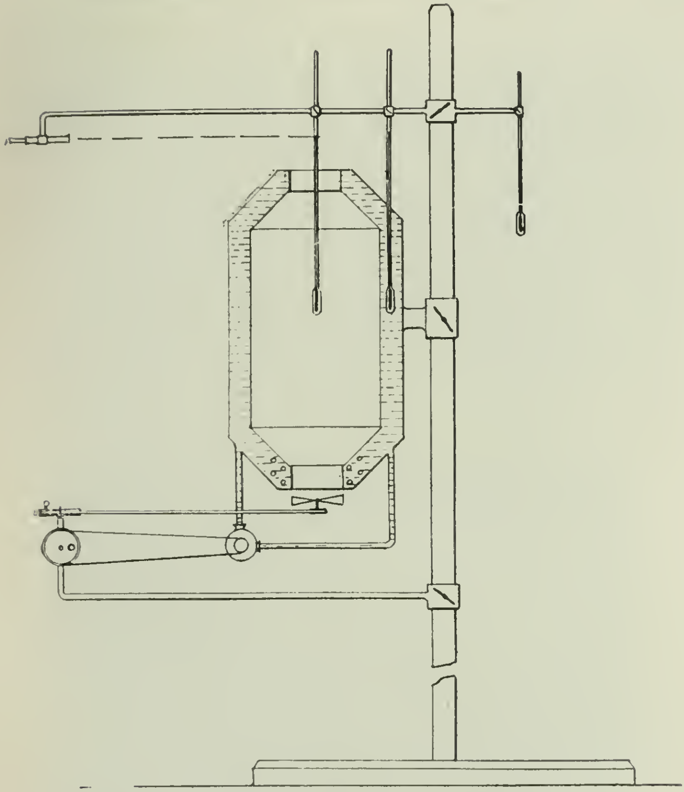


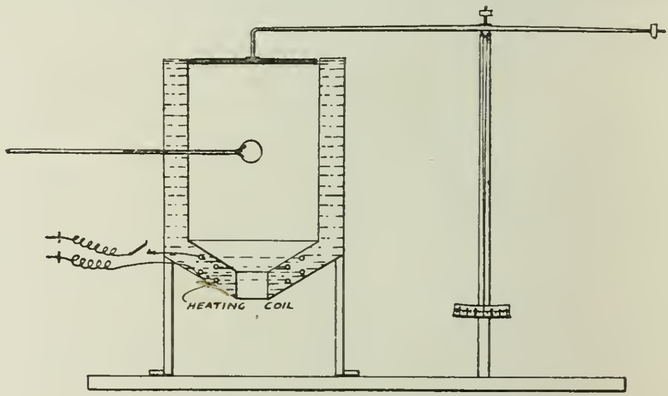
FIG. 1.—BARKER'S RADIANT THERMOMETER.

between the two walls, and providing means for heating it and stirring it powerfully. One delicate thermometer is inserted into the water-jacketed space and another into the water. The temperature of the water is then adjusted so that the inner thermometer reads the same whether it is surrounded by the water jacket or suspended freely in the open room. The temperature of the water is then clearly the "mean radiant temperature."

The elaborate parts of the apparatus are the means suggested by experience for ensuring that the thermometer is actually surrounded by air of the same temperature as in the room (for, of course, contact with the warm or cold sides of the apparatus will affect the temperature of the air) and for stirring up the water and for convenience of manipulation.

To take the reading of this instrument in practice is not so simple a matter as it looks on account of certain difficulties which need not be further discussed.

Air Temperatures.—The instrument for finding the temperature of air (fig. 2) is similar in general principle, but is a direct-reading instrument. It is constructed on the principle that if a thermometer is surrounded not only by air at the same temperature as the air in the room, but also by double-walled surfaces at the same temperature as the air, the thermometer will read exactly the temperature of the air. That is, if the radiant temperature is artificially made identical with the air temperature, both will be the same as the thermometer reading. The identity of the temperature of the air in the instrument and the air in the room is obtained by measuring its density by a very delicate chemical balance. Any convenient method may be adopted for regulating the temperature of the water in the instrument, which is gradually raised until the density of the interior air is



BARKER'S AIR THERMOMETER
FIG. 2.

identical with the room air. The author claims to have proved by the aid of these instruments that the stuffy feeling which is often associated with systems of central heating is due largely, but not entirely, to the fact that the air temperature is too high and the radiant temperature too low. On the other hand, the freshness of a building depends on keeping the air temperature relatively low and the radiant temperature high.

It is fundamentally for this reason that a room warmed by an open fire is by many sensitive persons often felt to be much more comfortable than a room heated by a radiator. It is not necessarily due to the fact that the ventilation produced is more liberal except in so far as a continual inflow of cold air into a room tends to keep the air temperature low. If, for instance, we have in a room some means, such as an electrical stove, for generating a good deal of radiant energy, and at the same time a coil supplied

with a circulation of cold brine for keeping the air cool, we should have in the room conditions in some respects similar to those obtained by a warm fire and an inflow of cold air. It is the *temperature* and humidity of the air which are the important points, and not its chemical freshness or freedom from CO_2 or other organic products.

Dr. Leonard Hill has shown by experiment that physiologically speaking the chemical composition of the air has within wide limits no effects whatever on the human organism, and the author's experiments bear out that fact from another point of view. Dr. Hill believes that the effect of ventilation is so largely a question of the rate at which heat is abstracted from the human body that all other effects combined are of comparatively small importance. He has devised two instruments to determine this rate of heat loss in any conditions.

FIG. 3.

The first of these is essentially a calorimeter consisting merely of a thermometer with a very large bulb. It is used by noting the rate of fall of temperature when raised approximately to the temperature of the human body and placed in the conditions which are under investigation. The rate of fall of temperature gives a measure of that at which heat is lost from the body.

A second and much more elaborate instrument is called the "caleometer." This is an electrical instrument which measures the rate of expenditure of electrical energy necessary to maintain

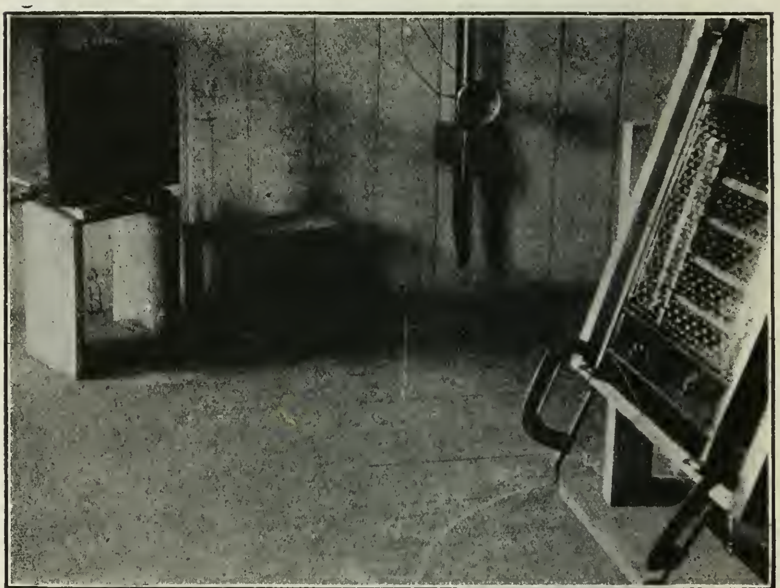


FIG. 4.

a coil at the approximate temperature of the body. If Dr. Hill's view is correct, the indications of these instruments are practically all that is necessary to determine whether the point at which they are placed is in a satisfactory condition as regards ventilation. The author believes that though this rate of heat-loss is no doubt of very great importance, yet there are many other conditions almost equally so. One of the chief is *the way* in which this surplus heat is abstracted. According to this view the proportion of the heat which is abstracted by contact of cold air with the body is of vital importance to the nervous sensations produced. It causes a great difference in effect whether the heat is abstracted by radiation or by contact of cold air. The amount

of heat abstracted by evaporation is also of great importance. This, again, is a problem of combined engineering and physiology which calls for a most difficult investigation.

In connection with this investigation it is obviously very important to be able to separate the amount of heat communicated to a room as radiant energy from that delivered by warming the air. We have designed and erected at the University College an apparatus (figs. 3 and 4) for this purpose, which has some points of interest. The heater under test is placed underneath a canopy which collects all the warm convection currents proceeding from it. A delicate electrical method is applied for testing its quantity and also its temperature. The stove is surrounded by radiant heat meters, such, for instance, as Smith's radiometer and thermopiles. The intensity of the radiation in any direction is thus obtained and plotted on polar diagrams (fig. 5), and a balance-sheet of the whole heat given off can be obtained with some accuracy by mechanical integration. In this diagram the distance from the origin to any point on the respective curves represents the intensity of the radiation in one particular direction. The scale represents deflections of the galvanometer due to the heat falling on a thermopile. The deflections are proportional to the intensity of the radiation. The proportion is determined by separate experiment. In this diagram, 10 scale divisions represent an intensity of radiant energy equivalent to 0·973 B.T.U. per square foot per hour at a radius of 5 ft. from the centre of the fire. That intensity all over the surface of a sphere of 5 ft. radius concentric with the centre of the fire may be represented on a system of polar coordinates by the surface of an irregular solid of such shape that the distance of the centre from any point on the surface of the solid represents the intensity of the radiation in that direction. It is the object of the diagram to represent this solid figure on a plane surface, not, however, by means of a system of contour lines, as usual, but by a kind of polar system of contour lines. The diagram is the plan of the field over which the radiation is playing. The origin is the centre of the radiating element. Each curve represents the intensity in a plane inclined to the horizontal at the given number of degrees marked on the respective lines. Each such plane is to be imagined rotated about a horizontal axis through the centre of the fire from its original inclined position into the horizontal plane. Thus each curve represents in its true size a radial section of the imaginary solid figure whose surface represents the variations in radiant intensity. By reversing the process the imaginary solid figure can be developed from this diagram by imagining each curve rotated back into its original position. The same apparatus is applied to

the investigation of the heat given off by a water and steam radiator.

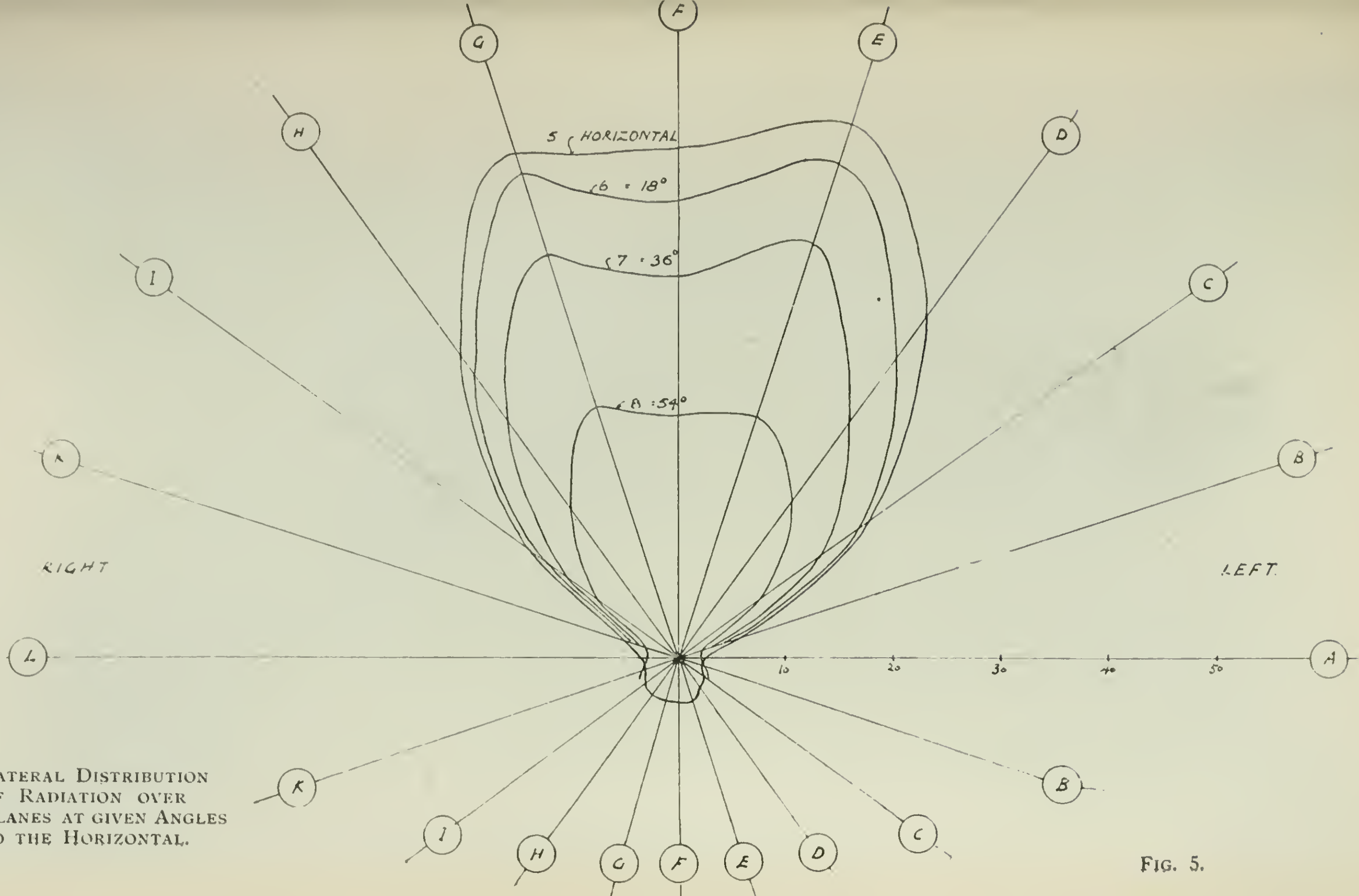
It will be understood that the above determinations (which are only a small part of the problems confronting the heating engineer) have had reference only to the measurement of the physical conditions of a room. They do not touch the question of the effect of these varying physical conditions on the body or the sensations of a person subjected to them. That is an aspect of the matter which, as has been said above, cannot be adequately treated by the engineer. It is essentially a problem of experimental physiology.

It will be evident also that the problems of heating and ventilation are closely associated. We cannot even consider problems of heating without simultaneously considering those of ventilation. We have, for instance, to consider the effect on the human organism of warm air and cold air. In this connection some very interesting experiments have been made by Dr. Leonard Hill in which he has studied the difference in the effect on the organs of the body of hot and cold air by actually inspecting those organs by optical instruments under different air conditions.

A further important point in connection with ventilation is to determine the effect on the human organism of different quantities of dust in the air. The investigation of such a matter naturally imposes on us the necessity of determining with some accuracy how many particles of dust do exist in a particular sample of air. As this number runs into millions per cubic inch, it will be evident that very special methods are required for counting them. The "Aitken" dust-counter (fig. 6) effects this, being based on the principle of measuring off a certain minute sample of air, and diluting it largely with a measured quantity of pure and dustless air. A certain fraction of this enlarged volume is measured off. The whole of the particles of dust in this fraction are deposited on a glass plate underneath a microscope and a measured fraction of these particles is actually counted. By multiplying up the total number in a cubic inch the original sample can be calculated. The method by which the particles of dust are deposited is to surround each with a globule of condensed moisture which so adds to the weight of the particle that it sinks and adheres to the plate.

The measurement of the dust particles is clearly only one side of the problem. We have also to measure the effect of different degrees of dustiness on the human organism. That is obviously a matter of great difficulty and concerns the physiologist and is more appropriate to the physiological than to the engineering laboratory.

In no respect has the science of heating and ventilation



Lateral Distribution of Radiation over Planes at given Angles to the Horizontal.

Fig. 5.

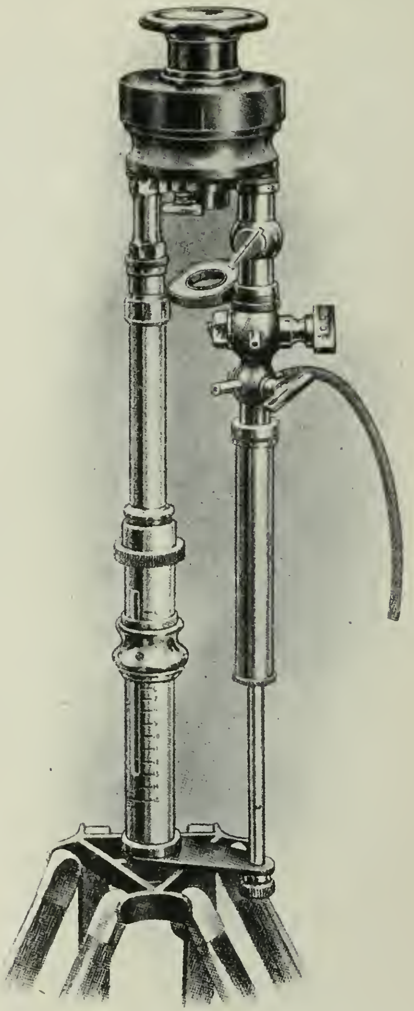


FIG. 6.—AITKEN DUST COUNTER.

been more backward than in the knowledge of laws governing the movements of air. If we compare, for instance, what is known of the laws of electrical currents with the corresponding laws of pneumatic flow, we shall see that in the one case the knowledge is for practical purposes complete and definite, enabling calculations to be made with the utmost precision and, what is more important, enabling the results of the calculations to be carried out in practice.

Pneumatic matters on the other hand have been treated with almost a casual indifference by the engineer. One reason for this is, no doubt, the fact that the effects of electrical flow can be exactly and precisely traced by self-contained instruments, often or generally of direct reading type. The flow of air, on the other hand, is not only extremely difficult to measure, but also very erratic. Further, it is not so vitally important to be able to measure with close accuracy the flow of air as is the case with electricity. No man will be suffocated if he gets 10 per cent. less air than was calculated. It would, indeed, be very difficult to show, experimentally, within 10 per cent., how much air he was actually receiving. But if a dynamo gave 10 per cent. less electrical power than was calculated on, there would be trouble. It would be quite easy to show that the maker of the dynamo had failed in his undertaking.

The flow of air is brought about by the operation of very trifling momentary causes constantly varying. So no doubt is the flow of electricity in relatively large quantities at low voltages. The ventilating engineer is concerned with a comparatively large flow of air at very low differences of potential. The problem is comparable with the investigation of the flow of electrical currents in a large mass of metal. If, for instance, we take a cube of copper measuring 3 ft. in every direction, the electrician would find very great difficulty in investigating the electrical currents throughout the mass. Some local circuits would no doubt be set up by any accidental distribution of electro-motive force, such as those set up by the movements of a magnet in the neighbourhood. This exactly corresponds to the problem with which the ventilating engineer is confronted in ventilating a building. Air is introduced for instance, into a room at a certain point. At other points in the room, sometimes near, sometimes remote from the point at which the air is introduced, currents of air are experienced which the occupants of the room call " draughts " which may, or may not, have something to do with the manner of its introduction. It is held up as a reproach to the ventilating engineer that these draughts exist, and so no doubt it is. He is told that he does not understand his business, because these draughts seem to be erratic, and that he cannot exactly control them. Yet the laws of pneumatics, little as they have been studied, are quite as definite as are those of electricity. The difficulty is that the conditions are so difficult to gauge and to control. The laws of pneumatic resistance have been put forward by the investigators in such a form that they are somewhat difficult to grasp by the comparatively non-mathematical mind of the engineer.

We are making an effort at the University College in the Department of Heating and Ventilating Engineering to develope

experimentally the laws of pneumatics on a somewhat similar basis to those of electricity as first suggested, the author believes, by Dr. Shaw. We are taking the fundamental formulæ in a form comparable to Ohms law ($E = CR$), viz. :—

$$H = RQ^2$$

and experimentally testing the validity of this law in all kinds of pneumatic flow.

This involves first the evolution of standard units of pneumatic measurement comparable with those of electrical science. For instance the unit of aeromotive force is naturally a foot of air column or that difference of pneumatic pressure against which it would require one foot pound of work to force one pound weight of air. The unit of flow (Q) is naturally one cubic foot of air per second. The corresponding unit of resistance is closely equal to the resistance of a round hole 6 in. diameter in a flat thin plate. The connection between these units is that a pressure equal to one foot of air column will cause a flow of one cubic foot per second through a round hole in a flat plate 6 in. diameter.

Now, obviously, if we can compare all pneumatic resistances with this unit, we shall be in a very much better position to understand the flow of air than we are at present, having to work with relatively complicated formulæ such as have been indicated. The fundamental difference between the laws of pneumatic flow and those of electrical flow are that in the pneumatic case the aero-motive force is nearly, but not exactly, proportional to the square of the flow, whereas with electricity the electro-motive force is exactly proportional to the first power of the flow.

This introduces certain differences into the mathematical treatment of the two problems, but these differences are not sufficient to exclude from possibility the application of some similar experimental methods.

We have, for instance, made a large apparatus, the pneumatic analogue of the Wheatstone bridge, for the determination of pneumatic resistances, and sundry methods of battery resistance have been applied to determine the internal resistance of a fan.

The great importance of this method to the practical engineer will be at once obvious. If for instance, we can specify the proper resistance in pneumatic units for a boiler flue and chimney we shall be in a position to deal on a rational basis with the much vexed problem of chimney shafts, which problem has been treated only in the most incomplete and perfunctory manner up to the present. We can determine by the application of these rules what is the actual resistance of a boiler flue, and are able to tell exactly what is the maximum capacity of a plant in heat, units or in lb. of steam, even without lighting the fire in the boiler.

The method by which this is done is exactly analogous to

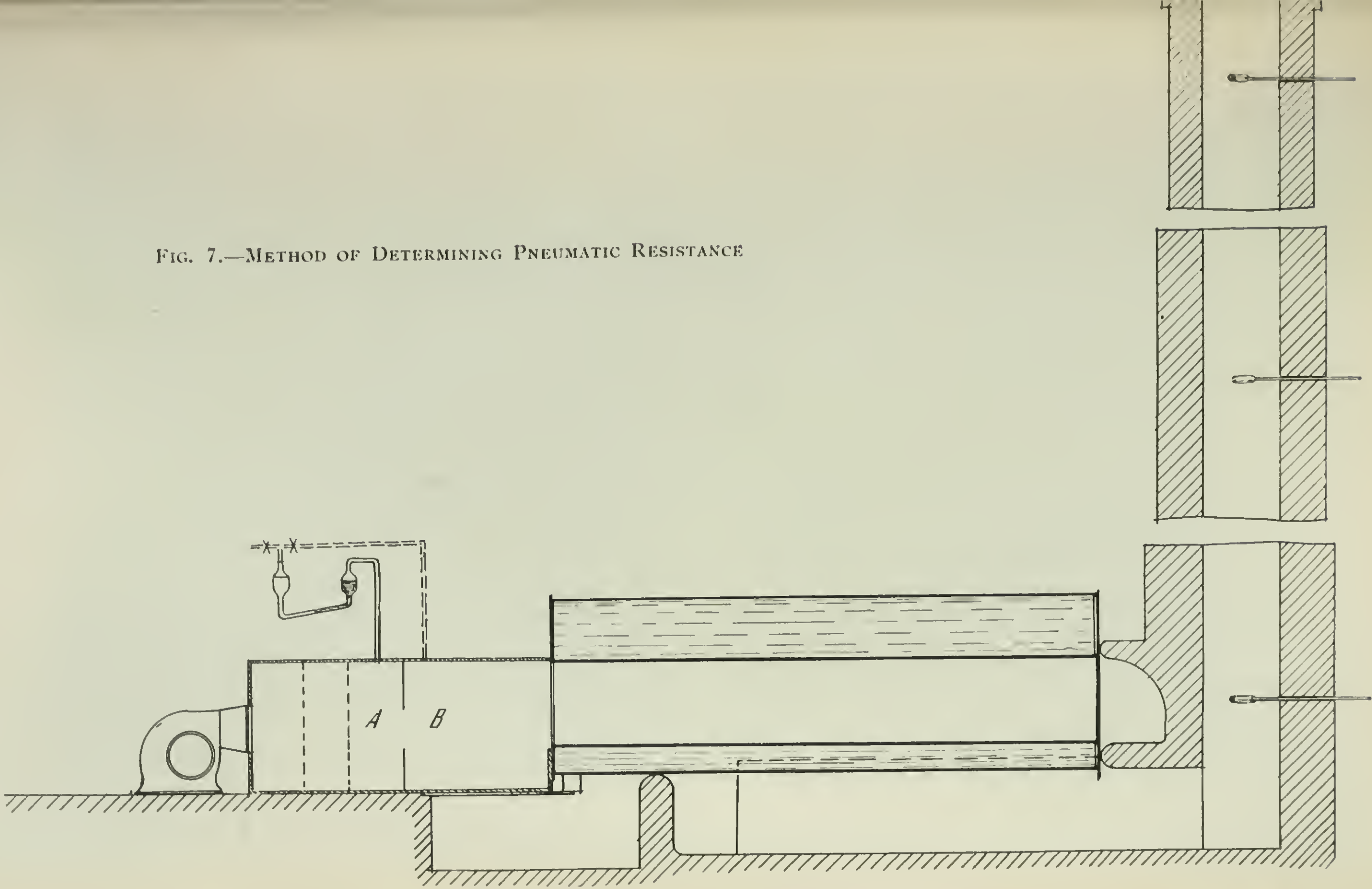


Fig. 7.—Method of Determining Pneumatic Resistance

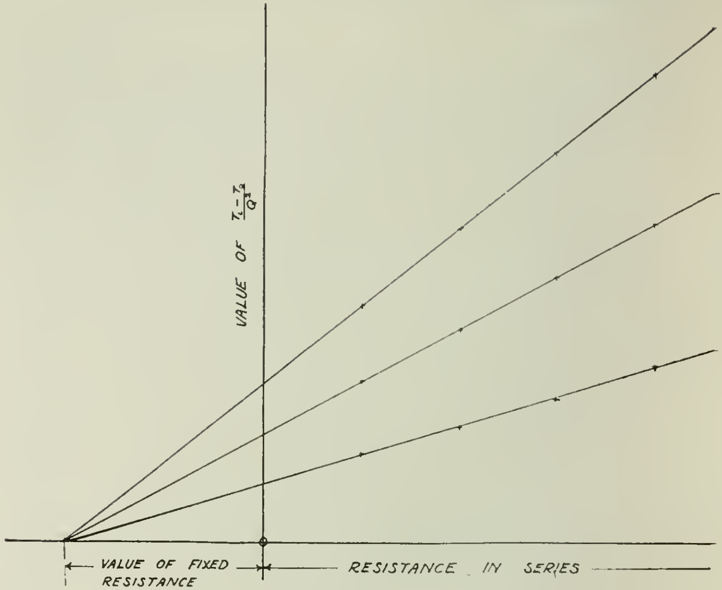


Fig. 8.

the potential method of determining battery resistance, namely by introducing into the battery circuit a number of different resistances which can be exactly measured and observing the currents produced in each case. To apply this method to the determination of the resistance of boiler flues and chimney shaft it is only necessary to adapt a fan to the air inlet to the boiler through a chamber in which a constant low pressure of air can be maintained. An adjustable resistance between the fan and the boiler inlet is then altered and the current measured in several cases from which the pneumatic resistance can be at once established. It is easy to show, for instance, that the total resistance of a plant consisting of say, three Lancashire boilers, 28 ft. by 7 ft. 6 in. should be about ·00172 units of resistance with a chimney height of 100 ft.

It is even possible to determine the value of the resistance without a fan, without even an anemometer, but having a very accurate micrometer pressure gauge. The method by which this is done will be apparent from the diagram. We need measurements of the mean temperature in the chimney from which we can determine the total aero-motive force by calculation. By measuring with accuracy the pressure in the chambers marked A and B (fig. 7). due to the pull of the chimney shaft, it is possible to determine exactly the flow of air through the flues at any given moment by calculation only. A very small amount of calculation

will then determine the resistance of the boiler flues and shaft in pneumatic units. The same factor may be determined by graphical methods first suggested by Dr. Shaw (fig. 8). The principle of this diagram is as follows :—The essence of the proposed law of pneumatic resistance is that the number of units of resistance is equal to the aero-motive force divided by the square of the flow. If, therefore, we plot values of this ratio in a vertical direction and the resistance itself in a horizontal direction, we shall get a linear relation. The total resistance in series consists of the fixed constant resistance plus the adjustable and measurable artificial resistance. We can alter the latter as we please, and for each value measure the flow, whence we can calculate the corresponding value of $\frac{\text{aeromotive force}}{(\text{flow})^2}$, and plot the results on a diagram against abscissæ representing the known value of the variable resistance. It is evident that the fixed resistance will be given at a distance from the origin to the point of intersection of the lines with the base.

We have applied the same system in practice to a number of other important determinations. We have found ,for instance, the relative resistance of different types of ventilating gratings and flues of different radius and shape. The method, indeed, is capable of very wide extension.

This paper has dealt sketchily and, possibly, very inadequately with a few only of the multitudes of problems with which the real science of heating and ventilating engineering is concerned. Enough has been said to show to engineers that there is a good deal more in this subject than such a collection of mere rough rules of thumb as are to be found in the current literature, and that the subject is well worthy of taking its place among the most difficult of practical science. It is largely because scientific engineers have not, hitherto, taken this subject seriously that it is in a very backward state. It is at the present time in something like the condition that mechanical science was in at the time of Newton or electrical science at the time of Faraday. It would be very much to the advantage of mankind if engineers would take the subject more seriously.

Discussion.

The President said he was sure that, after the excellent paper which Mr. Barker had just contributed, it would be the wish of the meeting to accord to the author a very hearty vote of thanks, and especially for having supplemented it by the instructive series of slides. The summit of the paper was reached in its last few lines : " There is a good deal more in this subject than such a collection of mere rough rules of thumb

as are to be found in the current literature." That statement would be subscribed to after hearing what Mr. Barker had had to say.

The vote of thanks was carried by acclamation.

Professor Leonard Hill, F.R.S., said he had listened with great interest to Mr. Barker's paper. They had worked together on the question of the ventilation of the House of Commons and, therefore, he was familiar with his work. The paper, however, contained much that was new to him, and that he desired to think over, and part of it concerned engineers much more than it did the physiologist. He was not sure whether one could take the reading of the radiant thermometer, as the author called it, as clearly indicating the mean radiant temperature; he was not sure whether the air which was blown through the box surrounding his thermometer, was not a factor in altering the radiant effect of the wall of the box. Further, there was the question of the emissivity of the walls of the chamber or room in which the thermometer was placed; the emissivity of the walls of the box must be considered.

He would like to say a few words on the physiology of ventilation. The present position of physiologists who had studied this subject was quite clear, namely, that the attainment of comfort and health by ventilation and heating of rooms and factories depended on the proper physical conditions and not on the chemical purity of the air. A report had recently been issued by a Commission in New York on the subject of ventilation. The Commission consisted of a professor of physiology, a professor of psychology, a professor of clinical medicine, a professor of chemistry, a ventilating engineer, and a member of the New York State Board of Hygiene—a strong Commission—and it had enquired into the whole subject. The report it had issued entirely agreed with the principles which had been laid down by physiologists in this country, and which had been upheld in Germany by Fluegge; *i.e.*, that the question was one as to the physical conditions of the atmosphere. He, of course, did not speak of factories in which poisonous fumes were given off, but ordinary factories and dwelling houses, and places of public resort, in which the contamination was due to the presence of human beings. In such conditions any increase in the percentage of carbonic acid or reduction of the percentage of oxygen was never such as to have any physiological influence upon us, even when rooms were crowded. There was no proof that anything of a poisonous chemical nature was exhaled in the human breath, as was stated to be the case in popular books on hygiene. One thing which really mattered in crowded rooms was the infection of one person from another by bacteria; this

was naturally a very serious problem. When a person suffering from influenza coughed or sneezed he projected a number of bacteria into the air, whence they were disseminated, and liable to be inhaled by anyone else, the danger being enhanced if the strain of bacilli was a virulent one. Colds and influenza were spread in this manner. And it must be remembered that persons might be carriers of a disease when they were not themselves suffering from it ; they might be carrying the germs of cerebro-spinal fever, or diphtheria in this way, *i.e.*, through harbouring the bacilli in the nose and mouth after they had recovered. The influence of dust had also to be considered, for dust was a most deleterious thing to the lungs, and it ought to be kept out of the atmosphere in every possible way. The continual stirring-up of dust in houses, and the dry-sweeping of public streets was much to be deprecated. The presence of dust in the lungs gradually lessened their efficiency and produced a tendency to asthmatic troubles as the person progressed in life. The presence of dust in the nose reduced its effectiveness as a filter ; the resistance of the mucous membrane was, thereby, lowered, and micro-organisms could gain an easier entrance and settle in the system. Dust containing free silica in particular was very damaging to the lungs, and those whose work lay among this dust were exceedingly liable to phthisis. People who motored and cycled at a furious pace along granite-covered roads, stirred up this irritating dust. All contamination of the atmosphere with dust should be lessened to the utmost. It must be remembered that the physical condition of the atmosphere acted on an enormous area of skin, and that the skin bore a multitude of cutaneous nerves which were very sensitive to changes of temperature and other atmospheric conditions such as humidity, and the net result of the messages thus conveyed to the brain was a general feeling of comfort, or the reverse. In the nose also were similar nerves, having their effect, according to the stimuli they received, on the general feelings of the person.

Another way in which the atmosphere had a profound effect upon us was, that the human body was a furnace which was burning up food and thus keeping the body warm. It was of the utmost importance to the individual that the human body should be kept working at a good rate ; that we should have to take plenty of active exercise to keep warm, thus ensuring proper metabolism in the muscles, and a vigorous breathing and circulation of the blood. The circulation of the blood was not brought about simply by the heart ; though the heart pumped the blood into the muscles and other tissues, the exercise of the muscles was the agency for sending the blood back again to the heart. People breathed more deeply because they wanted more oxygen to oxidize the food stuffs, and so to produce heat. The

increased flow of blood also hastened the elimination of carbonic acid and other waste products. An effect of all this was to produce increased immunity to infection. It was the sedentary workers in hot factories who did not breathe deeply enough, and who were thereby more liable to consumption and other bacterial invasions. Keeping in over-heated rooms and pursuing sedentary occupations reduced the metabolism of the body · the human machine was run at a low level, and the health suffered. If we wished to please our palates and indulge in the pleasures of the table, we loaded up our digestive organs with food which the body did not require under such conditions ; and that food was not all properly absorbed ; it got into the large bowel, where it underwent bacterial decomposition, producing toxic products, which were absorbed into the blood, impoverishing the health, and causing digestive troubles. Over-heating and over-eating were exceedingly bad things for us, especially when combined. The need was to keep the body metabolism by exposing ourselves to the open air as much as possible, and to the cooling effect of the wind, stimulating the taking of exercise, and leading to a complete digestion of the food. In order to do our work indoors properly, it was necessary to have the rooms at a comfortable temperature, but he advocated keeping up the body activity to the utmost extent ; we did not want to coddle, either in the matter of clothes or of heating of rooms ; the ideal was to keep oneself warm by bodily exercise. That was one of the great problems of ventilation, and we must compensate for the sedentary work in rooms by taking active exercise in the open air. In connection with ventilation, one of the important things was to find out at what rate the body was losing heat, and how it was losing it. Mr. Barker insisted on the necessity of knowing in what way the skin was losing heat, as well as the rate of that loss. It was lost from the body by evaporation, by convection, and by radiation. He, the speaker, had invented an instrument, which he called the Kata-thermometer. It consisted of a large-bulb spirit thermometer, which was heated over a spirit lamp, or hot water, until the spirit just rose into the upper reservoir ; then it was taken out and suspended in the atmosphere ; and as it cooled, the meniscus passed down the stem. He read how long it took for the meniscus to drop from the mark 100° F. to 95°, and in that way he got the rate of heat loss from a surface at body temperature. It was calibrated by Mr. O. W. Griffiths, physicist, by a special means, which he developed while working with the speaker. It was so arranged that one could read off the rate of heat loss in calories per sq. cm. per second. Each instrument had a factor of its own ; obviously no maker could make two instruments exactly alike. The instrument was used dry, and wet. It was covered with a

stockinette glove, and heated in hot water, and the excess of water was got rid of by giving it one or two jerks. Then it was suspended again, and one got the rate of heat loss while wet. When it was dry, it lost heat by radiation and convection, and when wet it lost it by evaporation in addition. The difference between the two readings gave the loss by evaporation. This instrument, he believed, was the only one to give an accurate and speedy measure of the rate of evaporation ; the determination could be carried out with great ease and speed. It gave, as far as they could judge, excellent results. If the instrument were put into a quartz tube, and this were evacuated to the utmost extent possible, the convection could be got rid of. In an experiment the vacuum was such that there was left only the one-four-millionth of an atmosphere. Having got rid of convection, he was able to determine the rate of cooling by radiation. The various factors could be separated and measured. The instrument brought out many interesting points : it showed, in a perfectly still atmosphere, that the evaporation from the surface of the body depended directly upon the vapour pressure of the atmosphere ; it had nothing to do with the temperature of the atmosphere.

Monotony was a thing which troubled us a good deal ; absolute monotony meant the absolute cessation of the working of the nervous system. When the avenues of sense were shut off, the person became unconscious. Monotonous conditions of the atmosphere made one sleepy, and reduced the vigour of the nervous system. It was desirable to measure whether the atmosphere was monotonous, or not. The instrument he now showed was designed to effect this, it was called the caleometer. He gave his ideas to Mr. O. W. Griffith and that gentleman, with great ingenuity, contrived this instrument. There was a little electrical furnace, which was automatically kept at body temperature, and a Wheatstone's bridge, in which was a galvanometer, acting as an indicator. In one arm of the Wheatstone bridge was placed this electrical furnace. There was also inserted another galvanometer, acting as a relay ; there was also a sliding rheostat. The mode of action was as follows : The little furnace was kept at a temperature of 40° C. by a current of 8 volts. If the temperature of the furnace began to get above 40°, the needle of the relay galvanometer swung over and completed the circuit through a magnetic coil, which attracted a sliding rheostat in such a way as to increase the resistance and send less current through the furnace, and so the furnace cooled. If the furnace temperature fell below 40°, the opposite happened, another coil being put into circuit, so as to alter the sliding rheostat in such a way as to increase the current through the furnace. The rate of heat loss was indicated

by the galvanometer, and if the atmosphere was lively the index swung backwards and forwards. In a monotonous atmosphere, the index took up a position at one end of the scale if it was too hot, and at the other end if it was too cold. The need was for an atmosphere which had the right rate of cooling ; and the rate of cooling should be produced to the right extent by convection, radiation, and evaporation ; each of these ways of losing heat acting on the sense organs of the skin. It ought to be known how much of the body heat should be lost by evaporation, convection and radiation. Evaporation was of importance, because the proper moisture of the skin and mucous membrane of the nose added to the person's comfort. We wanted the atmosphere to be lively, not monotonous. The ideal conditions out of doors were a cold variable breeze and radiant heat of the sun. Indoors we wanted to aim at securing radiant heat and cool air in gentle motion.

Mr. F. W. Goodenough desired to congratulate the author on his paper, which was one of great interest and excellence. It was, moreover, very much needed, for, as Mr. Barker said, the subject was in an extraordinarily backward state. Its intrinsic difficulties had been fully appreciated by the author, who said, truly, that this was one of the most difficult branches of practical science. The backwardness of the science—if it could at present be dignified by that name—was constantly being demonstrated. There was scarcely a new building erected in London without there being at once heard a grumble in regard to its ventilation ; a classical instance was that of the new "Old" Bailey. He had, indeed, seen comments in the electro-technical Press on the ventilation of the room in which they were now gathered. It was a source of surprise and reproach that the subject of ventilation was in such a rudimentary state. Whatever an architect planned in regard to a building's ventilation, it was largely a matter of speculation as to how it would answer ; he was blessed if it happened to turn out satisfactorily, but he could never be sure it would be so. Mr. Barker spoke of engineering being "glorified common-sense," but, perhaps, he would not object to add the words "plus knowledge" ; it was the common-sense application of knowledge. The complexity of this problem had been well realised by gas engineers, which profession he had the honour to represent. It was a constant source of trouble to them when dealing with gasfire problems and chimney draughts. A great factor was the constant diversity of weather. If one endeavoured to control the heating and ventilation by the human factor, it broke down at once. Most admirable systems of ventilation were found to be out of use a short time after they had been put into operation. It was,

therefore, necessary to deal with ventilation, for the greater number of rooms in the country, by natural means, and that was the principal difficulty, because there were such frequent changes of weather, of wind force and direction, and of humidity, to contend with, as well as differences in the degree of exposure of the premises themselves. One house might be on the top of a hill, and another in a sheltered position ; some houses were detached, some semi-detached, some completely attached as in a terrace, while some dwellings formed part of a block of flats. It was very difficult to arrive at set rules which would apply to all buildings. And the difficulties arising from internal conditions were scarcely less than those created by the external. As, for example, the presence or absence of a lift shaft made a good deal of difference to chimney draughts, for there was the question of suction or pressure opposing the ventilating arrangements. Similarly, two chimneys were often found to operate the one against the other. He was glad to see the author had given consideration to the psychology of this question ; it was a word and a science of which Englishmen had hitherto seemed rather shy, and he understood that applied also to the medical profession. But he was glad to see signs that its importance was beirg increasingly recognised. Mr. Barker's instance of self-deception in the case of the doctor was interesting, and one saw the same kind of thing in the case of Factory inspectors ; if they saw a flueless stove in a room, they at once concluded that the air was bad, though tests might show that the atmosphere was really being improved thereby, owing to their action increasing the air circulation. He was glad to see emphasized the point as to the difference to the comfort of inhabitants of a room according to whether heating was by radiation or by convection. It had been said there was no recognition of this difference in classical literature. By that he supposed that the author meant standard works on ventilation and heating. The literature of the gas industry was, perhaps, commercial rather than classical ; but, however, that might be there were plenty of places in that literature in which the difference between radiant and convected heat was fully recognised. The whole subject had been brought before gas engineers because of the unsatisfactory results obtained by the old-fashioned gas fires, which gave a great proportion of their heat in the form of high-temperature convection currents from chambers in the top of the stove, through which the products of combustion circulated, and gave only a small proportion of their heat by radiation. The physiological reason that was at the root of the dislike which many people had for that form of heating was the fact that by raising the temperature of the air in a room unduly, one also increased its capacity for retaining moisture, and so its thirst for moisture.

Hot air attacked the moist membranes of the eyes, nose and throat much more actively than did cool air, causing the well-known sensation of " dryness." Moreover, if there were cold objects in a room the air of which was hot, the body radiated its heat to those objects, while the hot air was absorbing moisture from the body, producing a state of affairs which was unpleasant, and probably also unhealthy. It was at the bottom of the criticisms directed against gas fires that they " dried " the air; it was not that the air was very dry, but that it had a greater capacity for absorbing moisture, and did so from the moist membranes of the body. Mr. Barker mentioned the case of the ice-cave in a glacier, and he, the speaker, had noticed a striking instance as shewing the negative effect of radiant heat on the temperature of the air. He had walked up a path in the Alps in the early part of the day, when the sun scorched him furiously on one side of the path, while in the shadow on the other side icicles were hanging, feet long. Immediately the sun's rays touched these icicles, they disappeared.

Dr. Leonard Hill had referred to the dispersion of the old " CO_2 bogy," and Mr. Barker said he had found air in a room feeling perfectly fresh with twenty-five parts of CO_2 per 10,000 present in it. But soda-water workers often worked in an atmosphere containing 300 parts of CO_2 per 10,000, and apparently without any physiological disability. An interesting problem for physiologists to explain was why the loss of heat from the body by air currents was more pleasing, and apparently more healthful, than loss of heat from the body by radiation to other bodies having a lower temperature. He agreed with Dr. Hill that the ideal for warmth and comfort was to be out on a Spring day, with the sun shining brightly and cold breezes blowing on one.

Mr. W. W. Nobbs said he believed it was the late Lord Kelvin who said that the more he learnt, the more he realised the limitations of that knowledge. It was, doubtless, in this spirit that the author placed before us some of the problems that await solution. Mr. A. A. Jones and himself were carrying out research work under Mr. Barker's direction, and, therefore, it were better for him not to express any opinion on these points but to preserve an open mind and thus avoid being influenced by preconceived notions.

As a heating and ventilating engineer, he was glad to see attention directed to difficulties that had to be overcome in this branch of science, and thought that the objects of the paper would be well served thereby. But it would be a mistake if, because of such difficulties, it were thought that no progress

had been made or that engineers were at a standstill until investigation has settled such points.

Though much remained to be done, good progress had been made in recent years ; CO_2 was no longer regarded as the malefactor but rather as a manifestor, while attention to humidity and dispersal of body heat were now regarded as of prime importance in every ventilating scheme that lent itself to such treatment.

He thought that while scientific investigation proceeded on the one hand, the psychological aspect should receive due consideration on the other, and every means adopted to educate those who will occupy properly ventilated apartments to appreciate the same by a knowledge of the fundamental principles involved, and thus create the *desire* for such places and the consequent sense of comfort when occupying them. In the evolution of all applied sciences, popular prejudice and fallacies have generally to be overcome. Probably no one present had had greater experience of this than Mr. Goodenough.

The practice of heating and ventilation had, in his view, reached a transitory stage that called for assistance from the allied professions and those interested in hygiene. Co-operation and assistance from the architectural profession was particularly desired. The modern architect might be likened to a director-in-chief and, as such, specialized in the production of a harmonious whole. For this purpose, besides having an intimate knowledge of his own profession, the architect was, or ought to be, conversant with the fundamentals of all the professions under his control; but it would be unreasonable to expect any one man to acquire the intimate knowledge of say six subjects that would be possessed by six individual specialists in those subjects. Consequently, in any large building of to-day, early and close co-operation was effected between architect and specialist in say, constructional ironwork, fireproof floors, hydraulic or other power equipment. The unfortunate omission in this respect seems to be the important one of ventilation. Most architects appeared to attach little importance to this, and efficiency was often sacrificed to appearance ; thus ventilating ducts and gratings were often hidden or placed in unsuitable places, while an unavoidable staunchion or beam was featured or harmoniously treated without question. He had little doubt that in buildings provided with fixed seating accommodation, adequate and economical ventilation would be met by a system of individual supply, but this could be seldom attained without help and early co-operation from the architect.

It was a growing practice, particularly in America, to recirculate the air from rooms such as class-rooms, in order to conserve the heat units contained in that air. The excuse for

so doing was based on modern research work which had shown that there was nothing deleterious in the exhaled air of a *healthy* person. This appeared to him to be a dangerous practice and one to be strongly deprecated, for it was obvious that in such an installation, the germs or whatnot from one infectious person would be soon distributed throughout the building. He did not consider this practice excusable because water-spray filters were sometimes installed, for he knew of no evidence that such would eliminate positively the air-borne germs, even when the water for the sprays was treated chemically.

Mr. E. R. Dolby said he agreed that the general body of engineers had not thought the subject of heating and ventilation of very great importance. Some years ago he wrote a paper for the Institution of Civil Engineers, and was considerably disappointed that there was such a poor discussion, and that so few of the members seemed to take an interest in the subject. A good deal more attention had been paid to it on the Continent and in America, and he put that down to the more severe climatic conditions prevailing there ; he did not think it had anything to do with the relative ability of Britishers and foreigners. As a consulting engineer, his work was chiefly in connection with public institutions, and much of it was in relation to hospitals ; therefore, he was anxious to know what there was in the present paper which would help him to improve the conditions in hospital heating and ventilation. He took it that the author's ideal was to have air at a low temperature, and to warm the rooms as much as possible by radiant heat alone. He asked those present to look at the conditions in various hospitals. Some years ago he went round the Birmingham Hospital with a deputation ; it was heated on the plenum system. The remark of one of the visitors put the matter in a nutshell when he said the atmosphere tasted like second-hand air. Recently, he was visiting one of the new military hospitals at Cambridge. There was no attempt to heat any of the pavilions which ran East and West ; the South side of each pavilion being open to the atmosphere, with simply an awning to prevent the rain from driving in. On enquiring how the patients and nurses had fared during the severe weather, he was told they put on more clothing.

Until recent years it had been the practice to heat wards by means of stoves placed on the central axis, and means were often provided for bringing in fresh air and warming this air also ; hence there was radiant heat as well as heated air. This system had been done away with, to a considerable extent, because of the difficulty of heating beds near the walls. He had found the best results were obtained by hot-water radiators, at a com-

paratively low temperature. One set out with the assumption that the temperature of a ward must be maintained at about 60° F., and that requirement he had tried to comply with. He remembered an instance which showed the difficulty of heating these wards satisfactorily. After the apparatus had been installed a month or two, there was a spell of cold weather, and he received a letter from the Superintendent stating that it was impossible to keep the temperature above 54°. He paid a visit without notice, and found the hopper lights above the windows on both sides wide open so that the ward was open to the wind When told about it, the Medical Superintendent said he must have the windows open as there were many aged patients—it was a poor-law institution—defæcating all over the place, and the atmosphere would be stifling. Those who had to deal with the matter practically realised how difficult it was to attain the ideal conditions recommended by the Author.

Mr. Alan E. Munby said he was an architect, and as he did not see in the room any other member of his profession, he would like to reply to some unkind things which had been said about architects by Mr. Nobbs. It was not fair to say the architect surrounded himself with various firms who designed the building for him. He had beams where he designed they should be; he had them placed where he wanted them. With regard to ventilation, there was this to be said for the architect: when the ventilating engineer came along, he generally had a scheme of ventilating pipes some 12 or 24 inches in diameter for carrying the air, or he wanted a duct under the floor about 4 ft. by 6 ft., and as it was required to run right round the building, it presented considerable constructional difficulties. He expressed his thanks for the privilege of hearing Mr. Barker's paper. He had been glad to hear the author devote so much attention to radiant energy. Though architects were not supposed to know anything about these matters, he had always felt that radiant heat was the form to be aimed at. He had regarded a frosty day with the sun shining as ideal health conditions, and he had wondered whether it would be possible to have a white-hot sphere suspended in the middle of a room for heating and ventilating purposes, though there would have to be some means of getting rid of the fried microbes. He believed there was a hall in Paris in which the heating was entirely effected by radiation from a double wall, into the space between which hot air was forced shortly before the hall was required to be used, and the radiation from which kept the room at a comfortable temperature. He was also glad to hear Mr. Barker refer to Dr. Shaw's paper. It was called "My Last Will and Testament on the Subject of Ventilation." It was sent to him to review for a journal. It was

rather beyond him, and he reviewed it enthusiastically, and that journal had never since sent him anything else to review. He was, therefore, particularly glad now that it was shewn to have been a good thing. He had always regarded Dr. Shaw's contention as to the relations between the air currents and the electrical data as very fruitful.

A practical point concerned the possibility of going back to the old system which the Romans used, of heating rooms by means of hot air driven through floors and walls. In these days of hollow terra-cotta floors, space was wasted by not utilising them for driving in air at high temperatures. A firm of engineers were working out a scheme for him in connection with a prospective building, in which they were trying to see how far the heating could be brought about in that way. It was being worked out by means of hot-water pipes laid in trenches in the floor. His idea was to have a thin layer of cement only, and cover the floor with linoleum. It would overcome many difficulties in these days when the windows of schools reached almost to the floor, so that there was no room to place radiators there. Engineers must give them something which did not require more than a vertical foot of space to stand against such windows. He would be glad to hear expressions of opinion on that method.

Dr. James Kerr said the complexity of this subject had been the cause of trouble for many years. Two functions were connected with air: respiration and ventilation. By separating those, one excluded questions of the chemical composition, and the carbonic acid question. The process of living involved changes which led to CO_2 being given off from the lungs and removed by means of the air. It also meant the production of heat, which had to be removed, and that took place mostly through the skin, at 300 to 400 units per hour, and the aim was to remove it comfortably; the skin temperature should be kept fairly equable. People could tolerate enormous ranges of temperature without discomfort; boys ran about on the Alps at very low temperatures. The author suggested 54° as a comfortable temperature. In London schools it was 58°; in New York schools 68°. 80 per cent. of New York offices were found to have a temperature of 70° to 80°; and there were people who enjoyed a Turkish bath. The removal of heat from the skin without discomfort was done by conversion of heat into a latent form, by evaporation, which meant convection. He did not see why if we wanted to remove heat by radiation we wore clothes or supplied heat to rooms; as the subject developed it would become a question of removal of heat by convection rather than radiation. Clothes should be worn to

facilitate the movement of air over the body. For this reason the present system of female neck-wear was more hygienic than men's tight collars. The problem of efficient ventilation would come down to an engineering one, of moving the cool air in a room, which was, for comfort, warmed by radiation. Schools which were mechanically ventilated were physiologically failures, because the heat was delivered considerably above the body temperature ; efforts were made to moisten the air, when perhaps it was not necessary, and it became like supplying a thirsty man with salt water to drink. A method of heating the floors so as to keep the feet warm was a good one, and some of the Derbyshire schools were heated on that principle. If those points were considered, we should no longer use hot air to warm rooms, but would supply cool dry air, and keep it in movement, so that it did not stagnate ; it would take away films of air in contact with the body, and remove the heat with them, and the body would be kept comfortable by radiation from the walls.

Mr. J. G. Clark, alluding to the author's psychological experiment upon his doctor friend, was reminded of a personal experience. Being interested in an experiment in a workshop he found there one day so high a temperature as to be really uncomfortable—well over 70°. The workmen did not think it too warm and for confirmation they referred to a thermometer which stood at 62° F., but was quite 10° below the proper reading. He had an accurate thermometer substituted and on calling there a day or two after he found an experiment spoiled by the premature turning off of the heating apparatus, although the temperature was not higher than on the day first referred to. The existence of such great influence of mind over body made one almost despair of satisfying everybody.

The author had mentioned the twin sciences, heating and ventilation. He would add lighting and so make a triple group. Lighting had an enormous effect on the mental attitude of people, and influenced them as regarded their appreciation of heating and ventilation. Probably a little more was known about the laws of light than about heating and air movements, but there was still a good deal to learn as to what constituted good lighting.

Dr. Hill's researches had gone far to elucidate the principles of ventilation and warming, and included, he understood, the relation between temperature, humidity, air movement and composition, and their compensating effects on each other. This seemed to indicate that there might be an infinite number of conditions of equal hygienic value. For instance, a very humid atmosphere might be unpleasant if the air were still, but would be comfortable with a certain amount of movement.

On the other hand a dry air might be quite comfortable if still but very unpleasant if in motion. They all knew the difference between a cold air and a cold wind.

The importance of variety or absence of monotony had been made clear by Dr. Hill. Heating engineers who had had experience with thermostats would realise the wonderful thermostatic action of the human body in maintaining constancy of body heat under extreme external conditions. In practice he had always favoured the provision of adequate heating power under easy control, so that the person most interested could, within certain limits, choose whatever degree of heat suited best. Radiant heat seemed to some extent to provide against monotony. A gas fire, for instance, radiated its heat differently in different directions, and in crossing a room a person intercepted beams of radiant heat of varying intensity and so experienced a variable sensation. Where heating was done entirely by convection very little variety was found.

He agreed with the author's statement that probably a judicious mixture of radiant and convected heat was the best, and his experience led him to believe that the proportion should be of the order of three of radiant and one of convected heat. Modern gas fires yielded their heat in approximately this proportion.

The question of dust was important in connection with heating, for dust imposed very definite limits upon the extent to which air could be safely heated for distribution by convection. It underwent chemical decomposition if unduly heated and so produced acrid odours. A large amount of this dust had its origin in the domestic coal grate. The "Lancet" had, for some months past, published reports of atmospheric pollution in different parts of the country, and the presence of tarry substances and ammonia clearly pointed to defective coal combustion as its origin. It might be concluded that any method of heating that precluded the use of coal would tend to eliminate a large part of the dust trouble.

Mr. A. S. E. Ackermann wrote saying that with regard to the "temperature of a room" to which the Author referred on page 117, this was on a par with the so-called "temperature in the Sun." When a thermometer is exposed to solar radiation its reading is merely a temperature to which it attains when the heat which it receives from the Sun is equal to that which it loses by radiation and conduction. The fact that if the bulb of such a thermometer be blacked the reading is raised, shows that the so-called "temperature in the Sun" has no very definite meaning.

As to what are comfortable conditions from an atmospheric point of view, it is remarkable how different these conditions may be according to circumstances. For example, in Cairo in July and August, 1913, the usual temperature in the shade during the day was 100° F., with several variations to 102° F., and two to 106° F. With almost equal constancy the temperature at night fell to 85° F. In the day-time the average speed of the wind was 5 miles per hour, and in the evening it was probably 2 or 3 miles per hour. The humidity in the day-time varied from 31 per cent. to 63 per cent. At night the humidity was not measured. The clothes worn in the day-time and at night were sometimes the same, and at all times of the same material and thickness, and while the days felt undoubtedly hot, but not unpleasant, the nights were perfect. One did not wish for even a microscopic change in the temperature, breeze, or the humidity in the evenings when sitting in the Esbekieh Gardens in Cairo. Another curious fact was that at Luxor, 450 miles nearer the Equator, the day readings of the wet and dry bulb thermometer and the wind speed were practically the same as those at Cairo, but the discomfort from the heat was very much greater. This may have been due partly to the fact that there was no relief from the atmospheric temperature, for even at midnight it was 100° F.

On page 121, Mr. Barker asks the question "How is it that radiator heat is so distasteful to many persons?" This reminded him of the results of some careful tests he made in 1899 of part of the hot water radiator warming plant in the Nurses' Home of the Hospital for Sick Children, Great Ormond Street. The most remarkable of these results was the small percentage of heat supplied to the heater which was apparent in the air of the room heated, the figure being $10 \cdot 7\%$, that is:

$$\frac{\text{Apparent total heat given to the air of the dining room}}{\text{Total available heat of steam supplied to the heater}} = 10 \cdot 7\%$$

He said "apparent" because no doubt more heat was given to the air by the radiators, but some of this heat was abstracted from the air by the walls.

Another interesting quantity was:

$$\frac{\text{Apparent total heat radiated through the walls \& windows}}{\text{Total available heat of steam supplied to heater}} = 38 \cdot 7\%$$

While the word "apparent" had to appear in the numerators of each of these quantities for the reason stated, the sum of the two quantities, namely, $49 \cdot 4\%$ was a definite quantity and the efficiency of the system. It was only as to the proper division of this $49 \cdot 4\%$ that we were in any doubt. The heater which supplied the hot water to the radiators was a steam heated one.

$$\frac{\text{Heat discharged from the radiators}}{\text{Total available heat of the steam supplied to the heater}} = 49 \cdot 4\ \%$$

This was low because the room in which the tests were made was 300 ft. from the heater. The flow and return pipes were each $1\frac{1}{2}$ in. diam., and were covered by a layer of magnesium carbonate (in sections) 1 in. thick, and were in exposed corridors.

Mr. C. Humphrey Wingfield wrote that when the nature of the data required were so clearly realised and laid down as the Author had done, a great deal had been done to guide future investigators.

When reading the second paragraph on page 117 he could not help thinking of the Lecture-room of the Royal Institution where so many scientific discoveries had been made public. It might be better now, but when he knew it some fifteen years ago it was one of the worst ventilated rooms in London although under the control of some of our best physical scientists. This illustrated the Author's contention that there was a great lack of knowledge on the subject of ventilation.

With reference to the statement on page 119, that air which chemically was absolutely pure might, nevertheless, feel very stuffy, he remembered that an experiment was recorded in which some mice were confined in an air-tight receptacle and after a time the air became so impure that they showed distress. On its being replaced with a fresh supply they at once became lively. The experiment was again repeated but instead of a new supply being added the air was made to circulate through chemicals which absorbed the carbon and made air precisely the same—chemically—as at first. The mice did not revive in this chemically pure air but when an electric spark or two had been passed through it they were at once as fresh as ever. Evidently ionisation is important where vitality has to be supported. Everyone knows the sense of refreshment experienced after a thunder storm.

Mr. Wingfield was glad to see attention called on page 121 to the fact that owing to losing or gaining heat by radiation at the same time as gaining it from the ambient air, a thermometer did not, necessarily, give the exact temperature of the latter. He thought, however, that if used carefully a thermometer was still a useful guide for comparing the performances of heating apparatus.

The people who objected to "apparatus heat" generally detected the "smell of hot iron." Mr. Wingfield had found, many years ago, that this smell was caused by cooking dust which had settled on the iron during the interval which elapsed since it was last used. He entirely eliminated it in the case of some horizontal steam-heated pipes by having them dusted

each morning before admitting steam. He was, however, much interested by the Author's conclusion on page 124, as to the cause of discomfort.

The two instruments shewn in Figs. 1 and 2, seemed well adapted for their work but it would appear that a good deal of time would be taken up in "trial and error" approximations when using Fig. 1. He thought it would be possible to cheapen Fig. 2, perhaps, by substituting a different device for the chemical balance.

To temperature and humidity as conditions of health and comfort (page 125), he would add circulation, which he believed to be as important as either ; possibly more so. The last part of the paper showed that the Author was fully alive to this.

He knew of a church in which the ceiling was removed and the parts of the wall exposed to the interior air made higher. This new condition upset the circulation and the church had become exceedingly draughty—the cooled air descending the walls and floors towards the centre of the nave.

He had advised raising the hot water pipes from 5 to 10 feet above the floor. This, he was then told, had already been done for other reasons in a portion of the church and this was free from cold draughts. His advice had not been taken so far, for financial reasons. The Author had made out a good case for further experimental work and he hoped means would be found for carrying it out.

Reply.

Mr. A. H. Barker, in reply, said it was true that the passage of the air over the thermometer in the instrument exhibited would cause a definite difference in the thermometer reading, *i.e.*, it would cause the effect of the contact of air to be increased, and the contact with the air inside the instrument with the warm or cool interior walls of the instrument would affect the instrument reading of the surface temperature. He and his colleague were fully aware of the possibility of that defect ; but they had made close observations as to the magnitude of the error, and their view was that it was so small as not to matter much. The point was kept in view in the design ; there was a tube which delivered air out of contact with the inner surface of the cylinder, so it was impossible for the air to be otherwise than at the same temperature as the surrounding air.

The physiology of the subject was, of course, the basis on which the ventilating engineer should work. It was only from the physiology of the subject that the engineer could determine what conditions he ought to aim at producing. Professor Hill's remarks showed that the chief things which really mattered in connection with the air of the room were :—

1. The number of bacteria, and
2. The amount of dust in the room, in addition to
3. The conditions which determine the rate of heat loss.

As Professor Hill had pointed out, there were three ways in which heat was lost from the body, namely, by evaporation, convection, and radiation, and the rate of evaporation was dependent entirely on the vapour pressure in the surrounding air. The rate of heat loss by convection was determined solely by what he had called the " body temperature " of the air, and the amount of heat lost by radiation depended solely, as he thought, on the " radiant temperature." Now the heating engineer wished to find in figures what vapour pressure should be maintained in the air in order to secure a suitable rate of heat loss by evaporation, what air temperature in order to secure a suitable heat loss by convection, and what radiant temperature in order to secure a suitable heat loss by radiation. If they could know the desirable value of each of these three factors they might work towards them on an objective basis rather than a subjective one. The caleometer and the kata-thermometer, valuable as they are, of course, gave only the total rate of heat loss from these instruments. Their use for this purpose implied an assumption that the surface from which heat was lost was a sample of the body surface, but he was not sure how far that assumption was justifiable.

Then as regards monotony, it would be desirable, though hardly possible, for the physiologist to tell them what were the maximum and minimum velocities of air movement desirable in a room, and in what direction such movement should take place relatively to the body. Whether it was possible or not to control those currents with sufficient accuracy, of course, was another problem with which the engineer alone was concerned. If Professor Hill could give them a maximum and the minimum rate of heat loss which would produce a satisfactory " liveliness " in the atmosphere they would have gone far towards finding out what they wanted to know.

He was satisfied that gas engineers had proceeded further in the direction of measuring radiation than anyone else. Indeed, he sometimes thought that gas engineers were the only people who knew anything of practical use about radiant heat. Mr. Goodenough had called attention to the diversity of weather and the diversity of situations of rooms. He (the author) had suggested elsewhere that it might be possible to specify a figure indicating the degree of exposure of any given room due to its position, and also a figure which he had called the " weather factor," such that relative variation from the standard in the loss of heat from a room due solely to the influence of the weather might be determined by the weather factor, and that the " factor

of position " should be such that of two rooms situated in two different positions the variation in the heat loss from the standard value should be in the same proportion as the factor. He thought that an experienced heating engineer, when he saw a room could form a very good idea of the value of the " factor of position," though, of course, the weather factor would have to be a matter of calculation from meteorological observation.

One of the reasons for the undesirable effect of hot air was possibly that it took up moisture too readily, and therefore caused more heat loss in the form of evaporation than was desirable. This might well be one of the elements in the problems, but according to Professor Hill the *vapour pressure* was the sole factor which determined the rate of evaporation from the body. Now, the vapour pressure was not considerably altered by a rise in temperature. He was not, however, sure that he agreed with Professor Hill's view.

In regard to Hr. Hobb's indictment, there were some members of the architectural profession who were willing to take enormous trouble to satisfy any reasonable demands of the ventilating engineer, but if, as was sometimes the case, an architect had reason to believe that the ventilating engineer with whom he was working knew no more about the subject than himself, he was quite justified in declining to sacrifice his schemes of decoration or design in the interests of demands which might be unreasonable. He did not think that the American experiments to which Mr. Nobbs alluded, on re-circulating air from rooms, were particularly successful.

Mr. Dolby had raised the very practical point—What was there in this paper which would help to improve the conditions in hospital heating and ventilation. Might he point out that the paper was prepared ostensibly as a statement of the difficulties which Mr. Dolby, himself, and all other heating and ventilating engineers had in common ? It was " up to " them to design means for decreasing air temperatures and increasing radiant temperatures. He had made a small contribution to this object by bringing out the system of heating know as the " Panel " system, in which walls were heated direct by low temperature heated panels having a large superficial area. The direct object of this system was to increase the radiant temperature so that the air temperature might be kept low and the room still retain the feeling of warmth. Stoves in a hospital ward were a very great nuisance, and he was now advising on alterations in a large hospital in London with the express object of avoiding the use of such stoves. It was certain that there were many people who would not be satisfied with any form of heating or of ventilation which did not include open windows, and those who had trained themselves to tolerate the draughts inseparable from a system

of open windows had made a step in the right direction. One should keep the windows open as much as one's friends would endure without making a fuss, although many people in cold weather liked to have an open fire as well as a hot water radiator in a room with open windows. It was futile to point out to them that they were pouring heat into the room with the apparatus and throwing it away by opening the windows.

Mr. Munby had called attention to the old system which the Romans used of heating rooms by hot air driven through walls and floors. There was certainly a future as well as a past for this method of heating. If he could afford to do so he would endeavour to heat a house solely by that means as an experiment. Mr. Munby had also suggested a radiator which did not stand more than a foot high under the windows. Many years ago he patented a system of warming a room by surrounding it by a dummy skirting-board made of iron and hollow, in which water was to be circulated, but nothing was done with it on account of the great expense and difficulties of making joints.

Dr. Kerr's remarks were very interesting as showing the practical medical view of this subject, and he agreed most thoroughly with all his views.

Mr. Clark had described the facts of variation and monotony of conditions with considerable precision. The great problem before the gas engineer at present seemed to him to be an æsthetic one. The modern gas fire was not beautiful, indeed, compared to a coal fire, it was hideous.

Mr. Ackermann's remarks on the temperature conditions in Cairo provided an apt illustration of the extraordinary adaptability of the human organism to widely different conditions. If everybody who had Mr. Ackermann's opportunities would only make similar exact observations of the precise conditions of the climates in which he happened to find himself and report their effect, the problems to which he had alluded might be almost solved by collecting and analysing the evidence. He would have liked more particulars of Mr. Ackermann's method of test in the case of the Hospital for Sick Children. It seemed at first sight that so low an efficiency as 49% for a steam hot water system needed some explanation. His own experience of this class of apparatus would place the figure generally between 85% and 90%. It depended on the exact meaning attached to the expression "efficiency."

Mr. Wingfield's experiments on mice showed clearly that the electrical condition of the air is a most important and altogether unrecognised element in ventilation. He was making researches on this very matter.

Might he say in conclusion that he had been immensely gratified by the interest which this little paper had obviously aroused and with the able discussion which had taken place ?

VISIT TO WORKS OF MESSRS. EDISON AND SWAN, PONDERS END.

On June 17th members of the Society of Engineers (Incorporated) and their friends visited the works of the Edison & Swan Electric Light Company, Limited, at Ponders End, Middlesex.

The visitors had as their principal object to see the process of " Royal Ediswan " Electric Lamp manufacture, but also had an opportunity of visiting the Engineering Section where every department was working " to deliver the goods " such as switches, switchboards, instruments, and other electrical accessories required for Government use : extra hands and extended workshops have enabled the additional output to go ahead with very little interruption of their usual trade.

Since the amalgamation of the Edison and Swan Companies in the year 1883, great progress has been made in electric lamp manufacture. The principal constituent of a lamp is the filament, because on its strength, economy in current consumption, and amount of light given off depends success or failure.

The filament is, to-day, made principally from pure tungsten, wire-drawn, and it has been proved that this form of filament is exceedingly strong, will save 75 per cent. in current consumption against carbon filament lamps, and gives unexcelled brilliancy. Tungsten was, at one time, only procurable abroad, but can now be prepared from a tungsten concentrate obtainable in Cornwall, which enables the Ediswan Company to be absolutely independent of imported raw material. Briefly the tungsten in a powdered state is compressed under great hydraulic pressure into thin rectangular bars, which are kept at a very high temperature in a hydrogen flame, so that all impurities are removed. Then after electrical treatment, which makes the bars more solid, the material is ready for beating or swaging, which is carried out under great heat, and the finished article is a long thin rod of tungsten, which is gradually " drawn " down to the familiar thread-like wire seen in lamps. After the delicate process of assembling glass foot, stem, leading in wires, and supporting spiders (or arms) is completed, the filament is wound on the supporting spiders. In bulb lamps the upper supports for the filaments are of strong and rigid nickel wire ; the lower ones are of molybdenum, which is thinner and more elastic.

The next process is to fix the filament in the form of a " cage " into the bulb, into which it is hermetically sealed. The lamp is then exhausted of air by pumps producing the highest obtainable vacuum. The Ediswan Company is exceedingly well supplied with means for glass making, having three large houses in full working order and a fourth (10-pot house) just being

completed. The original small house used many years ago has also been re-opened. The ingredients and mixing of the glass are not disclosed to anyone, because it has been the work of highly skilled chemists to produce the present high quality glass used for Ediswan bulb making.

After the preparation of a " batch " it is put into a crucible in the furnace, the glass by this time being known as " molten metal." In making a bulb, one of the operatives dips his rod (hollow metal tube) in the molten glass and a sufficient quantity is deposited on the end. After a little blowing and motion through the air the partly blown glass is placed in a mould manipulated usually by a youth, then blown to the shape of a lamp in the mould. It is then knocked off the tube and sent to a sorting department where all imperfect bulbs are rejected. The Ediswan glass-houses are kept continuously running by eight hour shifts.

After the exhaustion of the lamps the next procedure is to measure the candle power and wattage on a photometer, after which the lamp is sent to be capped, the last stage being the etching on the glass bulb of the trademark, candle-power, etc.

The following impressions have been contributed by a lady visitor, as a supplement to the official description above.

The party left Liverpool Street at 1.05 p.m., arrived at Ponder's End at 1.58 p.m., and proceeded to the offices of the Company where they were met by Mr. Elliott (one of the Joint Sales Managers) and other members of the staff. The first part of the visit was occupied in inspecting the Engineering Department, where various automatic and hand machines were in operation. The manufacture of ammunition boxes, hand grenades, Admiralty switch-boxes, and numerous other articles were ample evidence of the patriotic work being done by this Department.

The visitors then passed through the Lamp Department, where an exhibit showing the successive stages in the manufacture of lamps, from the raw material to the finished article, was seen. The actual processes of making carbon and metal filament lamps were then viewed from beginning to end, and one was struck by the delicacy and quickness with which the women workers did their part of this work. The operation of testing the wattage and candle-power of the lamps was noticed by all to be a most tedious one. The last part of the visit was spent in the glass factories. Here one was impressed by the wonderful operations of glass blowing and the production of glass bulbs.

After a most delightful tea a vote of thanks to Mr. Elliott and the Company was proposed by Mr. Ackermann, seconded by Mr. Esson, and replied to by Mr. Elliott, and the party returned to town by the 5.19 p.m. train. P. P.

PUBLIC WATER SUPPLIES.*

By PERCY GRIFFITH, M.Inst.C.E., F.G.S., F.R.San.I.,
Vice-President.

IN a lecture of an hour's duration it is, of course, impossible to deal with this important subject in a comprehensive or exhaustive manner, nevertheless, with such a large reservoir of information to draw from, it should be possible to select such as will prove both interesting and instructive. It is therefore my intention to deal, on broad lines, with the principal types of schemes providing communities with supplies of pure water, and to show slides and cartoons illustrating features of actual works.

It is probable that most of you are accustomed to obtain a supply of water by turning on a tap, and that quite unconscious of the amount paid for this convenience, you consider the provision of public water supplies as one of the most elementary of engineering problems ; but if so, I am confident of proving the contrary to be the case ; moreover I shall be disappointed if I fail to awaken such an interest in the subject that some of those present will themselves aspire to become Water Engineers.

A comprehensive study of this subject will bring you into contact with almost every branch of science, will involve the investigation of almost every known law of nature, and will necessitate the study of many social and economic laws. Hence the prospective Water Engineer must commence by careful study of the mechanical and physical sciences, he must miss no opportunity of observing the fundamental laws of nature, he must acquire a practical knowledge of social and commercial principles, and, to secure prominence in the profession, must collect, absorb and apply information of all kinds from all sources with intelligent enthusiasm and untiring assiduity.

As the work of the Engineer is essentially that of "directing the great sources of power in nature for the use and convenience of man," I shall first deal with water as provided by nature, and shall then point out the main problems associated with the collection of the supplies necessary to provide for the needs of towns, villages and rural districts.

Water exists in a natural state in a great variety of forms, in greater variety, probably, than any other element in nature ; thus clouds, mist, dew, rain, hail, snow, ice, hoar-frost, and steam or aqueous vapour are all forms of water, and a study of

* A lecture delivered on February 24th, 1915, before the Birmingham University Engineering Society (affiliated to the Society of Engineers, Incorp.).

the physical and chemical phenomena associated with this remarkable element will afford, not only endless interest, but, to the prospective water engineer, a very necessary training for the special problems he will subsequently have to face.

In examining the evolution of water it will be seen that, while its *form* may vary between wide extremes, its *substance* is almost invariable, whether it be liquid, gaseous or solid, its essential constituents being ever the same, viz.: hydrogen and oxygen, combined as expressed by the familiar chemical sign, H_2O.

Under natural conditions water is constantly traversing a cycle of changes, of which the liquid form is only one and by no means the most important manifestation in the economy of nature. Under the combined efforts of sunshine and wind, and even without these phenomena, evaporation is constantly and invisibly taking place from the surface of every exposed piece of water, from the ocean itself to the smallest pond. The atmosphere takes up water in quantities which, if expressed in figures, would make the total delivery of all the pumps in the world seem trifling in comparison, indeed no figures can give an intelligible idea of the mechanical energy exerted by this single force of nature.

This vast quantity of water having been collected in the atmosphere as invisible vapour becomes subject to a great variety of influences which produce the many phenomena covered by the science of meteorology, but of these we can now consider only one; viz., the formation of clouds. Carried in invisible form to heights and into temperatures and pressures in which it can no longer remain invisible and impalpable, the water vapour condenses, first to fine white fleecy masses representing what I may call "fine weather" clouds, usually occurring at great heights, and then, under suitable conditions, to heavy, stormy cloud-masses which, by their greater density, fall to lower levels, and finally by a slight further condensation, become heavier than the atmosphere and fall to the earth either as rain, hail or snow.

Here, then, we have the first and most obvious source of supply; but at once do we meet with physical difficulties in utilizing the supply for ordinary public purposes. The rain falls impartially on land and sea, on mountains and valleys, on permeable and impermeable ground, on inhabited and uninhabited areas; moreover in falling through the lower reaches of the atmosphere it absorbs solid matters in varying stages of impurity, and becomes polluted to an extent that renders it unsuited for domestic use without treatment. Arrived on solid ground, the rain is subjected to a variety of physical conditions which produce a similar variety of results. By the most elementary of these conditions, the force of gravity, it seeks the readiest means of falling towards its ultimate goal,

the ocean, and in so doing it becomes diverted by a hundred different conditions, the study of which constitutes the first and most elementary branch of the water engineer's work.

Bearing in mind the obvious fact that water collected on high ground can be conveyed without pumping to any town at a low level, it would appear that the simplest schemes of water supply are those which, by intercepting the water before it can flow on to low ground, enable it to flow by gravitation to the desired point. Waterworks of this character are usually known as "Gravitation works," the source of supply being usually described as "Upland Gathering Grounds." With these I will deal more fully later on.

It will be very obvious, however, that of the total rainfall, only a small proportion is available for use in this way, and the great bulk flows away, unhindered by any human agency, either to lower ground where it concentrates into large rivers, discharging direct to the ocean or through fissures or permeable strata into the earth's crust, there to form that most important source of public supplies: "underground water."

The subject of water works, therefore, naturally divides itself broadly into two parts (1) gravitation supplies from upland gathering grounds, and (2) surface and underground supplies requiring to be pumped. I will deal with these in turn. Meanwhile I must point out that as Nature but rarely provides pure water under conditions which dispense with the intervention of the water engineer, this profession is one of the most ancient known to man, and works executed hundreds of years ago, prove the substantial manner in which the early water engineers designed and carried out their works. These works were all of the "Gravitation" class, as pumping machinery was at that time unknown except on a small scale and in the form of elementary elevators worked by manual or animal powers.

(1). *Gravitation Supplies from Upland Gathering Grounds.* Although I have described this class of works as the simplest, it must not be assumed that schemes of this character can be designed and carried out without considerable study and experience. In the first place, they are proportionately far more costly than pumping schemes, but beyond this, failure involves consequences of a far more serious character, and the calculation of the available supply of water and the capacity of the reservoir, the selection of a suitable site for the embankment or dam, and finally the design and execution of the works themselves, involve difficulties which can be overcome only by the most elaborate investigation and careful study, and after many years' practical experience in subordinate capacities, under engineers in active practice.

I will now briefly deal with these points in the sequence stated.

Calculation of the available Suppy of Water and the Capacity of Reservoir required.—This matter is one involving some very interesting investigations, but it is first necessary to grasp the real purpose to be secured by the impounding reservoir, viz., the adjustment of the available supply to the demand. Now the daily demand in any given town varies considerably during the year, more so in purely residential areas than in those with manufactories or works using water for trade or manufacturing purposes. This variation is, however, more conveniently provided for by service reservoirs constructed either on adjacent high ground, or on towers in cases where no hills are available. As regards impounding reservoirs, therefore, we may assume the daily demand to be constant throughout the year, and may start by an assumed average daily demand to be provided for by the intended works. This figure must of course be large enough to provide for the anticipated increase during a period of years, as works of this character are too costly to be enlarged or duplicated at short intervals, as may be done with pumping schemes.

Having arrived at the daily quantity to be provided at the reservoir outlet it remains to be determined what capacity of reservoir is necessary to secure such a supply from a constantly varying inflow from rainfall. The most certain method of doing this is by gauging the flow of the stream draining the watershed at a point corresponding to the site of the dam.

A difficulty arises in gauging the flow when there is a wide difference between the maximum and minimum flow, because when the stream of water flowing over the notch is less than 3 inches or more than 2 feet the formula from which the rate of flow is obtained becomes inapplicable. In streams liable to heavy floods, therefore, the weir should be provided with movable sides or it may be stepped along its length. It is important to provide a large and deep reservoir on the up-stream side of the weir to prevent the water from approaching the notch with any considerable surface velocity, the water must have a clear fall below the notch to allow free access of air to the underside of the discharging stream, and the depth of the stream passing over the notch—which is the co-efficient from which the flow of water is calculated—must be measured at a point some distance back from the notch, where the water is without appreciable movement. Various formulæ are available for calculating the flow from the depth of water passing over the sill, but they are too complicated to be explained in this short lecture.

It is, however, rarely possible to obtain sufficient records of the flow of streams to enable a reliable estimate to be made of the average, maximum, and minimum supply available, from which the capacity of the reservoir and of the overflow channel are calculated. Daily records over a long period of years would

alone give reliable data, and it is usual, therefore, to utilize rainfall records, If such records are not available for any particular watershed, it is possible, by comparing local gaugings taken over a comparatively short period with gaugings in similar watersheds where longer records are available, to deduce a fairly accurate estimate of the essential figures, that is to say, the average rainfall of three consecutive dry years, which is usually accepted as the basis for calculating the storage necessary in any given case.

In this country the amount of storage required—expressed in terms of $\frac{\text{Total Storage}}{\text{Daily Demand}}$ varies from 120 days to 250 days, but in tropical countries like India, it may be necessary to impound a quantity representing the total demand of a period extending to two years or more than 700 days.

In these calculations due allowance must be made for losses by evaporation and percolation. The former may in this country amount to from 12 inches to 27 inches calculated over the whole watershed or gathering ground, and varying according to the slope of the surface and the nature of the vegetation and subsoil. Loss by percolation should be prevented by carrying the watertight core of the dam down to solid rock throughout its length.

I must here say a few words as to the method of arriving at the average daily demand, which is the main factor in the calculations for storage capacity. This is usually expressed in terms of gallons per head of the population, but when it is realized that the supply to be provided must include water required for trade, manufacturing and other non-domestic purposes, it will be seen that no standard rate per head can be accepted as common to all cases. For purely residential districts the rate may vary from 15 to 20 gallons per head, but in industrial areas it may rise as high as 50 gallons per head, and in many American and Continental cities the consumption reaches 120 to 150 gallons per head of population. In London the average consumption is 36 gallons per head and this may be considered as a very liberal allowance for any area including both residential and industrial properties, while for rural areas without any appreciable trade demand, a supply of 15 gallons per head is ample.

Selection of Site for Impounding Reservoir.—This is a problem requiring experience and judgment for its solution, because the cost and efficiency of the scheme will depend very largely upon the relative suitability of the site selected, and a mistake at this stage may involve a vast increase in the cost of the works and even the risk of ultimate failure. If you are familiar with the mountains of Wales or Cumberland, you will realise at once

that the configuration of the smaller valleys affords everything necessary to the formation of an impounding reservoir except a wall or bank across a valley. The main question is therefore where a watertight bank or wall can be most effectively and economically constructed. The most important points for investigation are (1) the impermeability of the area to be covered by water, and (2) the possibility of constructing the dam so as to intercept the whole of the available yield of the gathering ground, in other words, Nature must provide a watertight basin or it is useless to endeavour to collect water in it. Fortunately these mountainous areas are usually formed of the older and deeper rocks which are for the most part impervious, but which are generally much "faulted" and fissured. Having ascertained by careful examination that the area of the intended reservoir is generally impervious, it is necessary to determine at what depth a homogeneous and impermeable rock will be found in which the base of the dam can be effectively sealed. This information is obtained by sinking trial holes (or wells), and borings at various points along and across the valley.

Suitable conditions having been found to exist, a contour survey of the valley immediately above the site or sites suggested for the dam must be made, in order to estimate the height of dam required to impound the quantity of water previously determined.

At this stage, consideration must also be given to other questions, such as the proximity of materials suitable for the construction of the dam, the existence of roads intersecting the area to be covered by the reservoir, the liability of the gathering ground to pollution, etc., and with this information it will be possible definitely to select the most suitable site for the dam, and this being settled, to proceed with the design of the works.

(*c*) *Design and execution of the Works.*—In "Gravitation" schemes the works comprise many important items besides the embankment or dam, as for example, a by-wash channel for diverting the stream from the reservoir in times of flood or during repairs, an overflow channel for releasing surplus water without injury to the dam, an outlet tunnel with pipes and valves for controlling the amount drawn from the reservoir, apparatus for regulating and measuring the quantity of "compensation" water, apparatus for filtering the water supplied to the town, the pipe line or conduit conveying the water to the town, etc., but in this short lecture I cannot do more than briefly refer to the construction of the embankment or dam and the works immediately connected with it.

There are (as no doubt you know) two types of dams, the embankment of earth with a core of puddled clay, and the masonry dam. The former is by far the most common, although not by any means the most picturesque, and for moderate

heights it may be looked upon as perfectly satisfactory and as more generally applicable than a masonry dam. A trench is first of all cut across the valley, extending to the solid rock, and the materials excavated from the trench must be distributed over the area representing the base of the embankment, as it is important that this large quantity of material should not have to be moved twice. The portion of the bank immediately adjacent to the puddle core must, however, be formed of specially selected material, and it is the special function of the engineer so to organize the work as it proceeds that a sound and efficient result may be obtained at a minimum of cost. You will observe that during the digging and filling of the trench the water flowing in the stream must be carried over the excavation by a temporary bridge, and it is important to see that this is constructed of sufficient capacity to carry the maximum flood which may occur during the period in question, otherwise the trench may be flooded and much loss of time and money result.

The trench being completed and a portion of the bank proportionate to the depth and width of the trench formed, the next step is the filling of the trench with either clay puddle or concrete. Engineers differ as to which is preferable, assuming both are equally available, but there is probably less skill required, both in the work itself and in its supervision, if puddle is used. At the same time concrete will be more generally available than clay, and the engineer must make a special study of the precautions necessary to secure watertight concrete, as this material is constantly required in the construction of waterworks. Having completed the filling of the trench, the bank and puddle core are then proceeded with. The work must be carried up as uniformly as possible throughout its length, the bank being formed in layers of about 3 feet thickness, each well consolidated before the next layer is added.

Through the lower portion of the bank is constructed the outlet tunnel, which is usually placed as nearly as possible adjacent to the original bed of the stream, in order to drain the lowest part of the reservoir. This tunnel will ultimately be provided with the outlet and wash-out pipes, and on the completion of the dam will be bricked up for a length of from 10 ft. to 20 ft. so as to prevent water escaping through it.

The design and construction of the overflow is particularly important in the case of earthern embankments, because should the overflow be insufficient to carry away flood water and the reservoir begin to overflow on to the earthwork, this would be rapidly washed away and the whole structure be in danger of collapse. Many terrible disasters have occurred from this cause, and it is therefore desirable to make very liberal estimates in calculating the maximum quantity of water to be provided for in the overflow and channel leading from it. In some cases the

overflow and its channel have been constructed in the adjacent hillside, so that these works are quite independent of the embankment, but of course this is a more costly method than the more usual practice of constructing the overflow at one end of the bank and carrying the channel down the angle formed by the bank and the hillside. The overflow and channel must, for obvious reasons, be constructed in masonry or concrete.

In a masonry dam the base of the dam must rest throughout its length and breadth on solid rock, and unless this can be formed comparatively near the surface, the cost of the work is likely to be prohibitive. The profile of the dam affords some scope for variety, and practice reveals many alternative types, but the calculations for stability are more or less identical with those involved in retaining walls. It is accepted as a maxim that the stresses forming the resultant of the water pressure and the weight of the structure should fall within the middle third of the section. Masonry dams, besides being more suitable for deeper reservoirs, offer the further advantage that, at but little extra cost, they may be so designed to permit of their being raised should further storage be required at a subsequent date.

Although there are many other points of interest connected with schemes for gravitation or upland supplies, I must now turn to the more varied and no less interesting subject of

Surface and Underground Supplies.—Although complete statistics are not yet published relative to the quantities of water obtained in this country from surface and underground sources respectively, I have no hesitation in saying that as regards water used for public supply purposes, the quantity obtained from underground sources is at least equal to that obtained from surface sources, and as a considerable proportion of the latter is pumped, there is little doubt that the public supplies obtained by pumping far exceed in amount those obtained by natural " gravitation." (I use the prefix " natural " here because *all* public supplies are *ultimately* distributed by gravitation, and in this case, I refer to those which do not require to be artificially raised by pumping).

In dealing thus broadly with the whole question I must not fail to mention a class of supply which is, strictly speaking, derived from underground sources, but which is nevertheless, often supplied by " natural " gravitation. I mean those supplies obtained from natural springs at a sufficient height to gravitate to the area supplied. In many villages and rural areas, sufficient water is obtained in this way to provide the relatively small demand which exists in such cases without either pumping or storage. Such schemes are not of sufficient importance to warrant any lengthy description here.

(*To be concluded.*)

VISIT TO THE NAPIER WORKS, ACTON.

On Tuesday the 13th inst., a party of members of the Society of Engineers (Incorporated), with their friends visited the works of Messrs. D. Napier & Son, Ltd., at Acton Vale.

The business was originally established in London in 1820, and after being carried on in Vine Street, Lambeth, for upwards of seventy years, the manufacture of motor cars was commenced, and so great became the demand, that it was found necessary to acquire further manufacturing space. The present site of about eight acres was secured and the works started in 1903.

The firm has been from its earliest existence associated with work of the highest mechanical order, demanding great precision. Gold coin weighing and classifying machines were their speciality for many years, and are still manufactured by them, being in use by many banks and Imperial Mints throughout the world. Messrs. Napier were the first to construct machines for making bullets, and bank-note and postage-stamp printing machines have also been manufactured by them in large numbers.

The lay-out of the factory at Acton Vale has been planned on the system of arranging the shops so that as far as possible operations shall follow in sequence to avoid loss of time in handling material during its stages of manufacture. The workshops, which are wholly on the ground level, are lighted by north light, and are well ventilated and warmed. They consist of two main sections: the machine shop, covering an area of approximately 7,500 square yards, contains upwards of six hundred machine tools, as well as a large tool room and a fine grinding section. An erecting and assembling shop slightly less in area contains the gear wheel cutting department and the finished stores. The sheet metal working department is also under this roof.

Surrounding these two main buildings are various subsidiary departments, comprising, among others, rough stores, pattern and carpenters' shops, smith and engine testing shop, foundry, die casting and hardening shops, engine testing shop, and raw material testing laboratory, view room, and new car-fitting department. A large building for the overhauling and renovating of customers' cars is run as a separate department on self-contained lines. The power necessary to drive the machinery is taken from the mains of the Metropolitan Electric Supply Co., the Napier Works own electric generating station being used as a reserve. This plant consists of a Willans-Diesel four-cylinder engine

and generator with an output of 200 K.W., a Ruston-Proctor horizontal compound steam engine and generating set of 250 K.W., and a National suction gas-engine of 60 K.W. Current is distributed to motors situated at various points in the works, each of which drives a group of machines through overhead shafting. The power house switchboard is so arranged that current from either the works plant or the town mains can be switched on to any section of machinery.

With a view to maintain the high order of work with which the firm has always been associated a very rigid system of inspection of raw material and work in progress is in operation. Raw material is subjected to a chemical analysis and to physical tests for tension and torsion on a Buckton machine; special tests are also carried out for resistance to impact and for hardness on a Brinell apparatus. Most valuable results are obtained from these tests and from the continued testing and inspection of assembled units, such as completed gear-boxes, rear-axles, and engines under conditions as nearly as possible approximating to the work they will be called upon to do when the parts are on the car. The motors are tested under load with Prony apparatus, and the complete chassis before being taken out for road tests are subjected to dynamometer tests for H.P. at the road wheels.

In the rough stores each bar of steel is classified by means of painting it in distinctive colours to denote its physical properties, and its subsequent identity is preserved by stamped marks. At the present time the factory is engaged on important work for the Government, including military transport lorries, ambulance cars, aeroplane engines, and aeroplanes.

PUBLIC WATER SUPPLIES.*

(Continued.)

By PERCY GRIFFITH, M.Inst.C.E., F.G.S., F.R.San.I., *Vice-President.*

As I have already indicated, the variety of sources other than upland gathering grounds is almost endless ; and the water engineer—at any rate the consulting engineer who professes to advise under all circumstances—must acquire a more than casual acquaintance with the science of geology—particularly hydro-geology (as distinguished from Paleontology, or the study of fossils.).

The flow of water through the various strata composing the external skin of the earth affords material for careful study and by its very variety will be found extremely fascinating, even apart from the question of water supply. The relative permeability of the surface and subsoil is a matter of vital importance to the farmer or student of agriculture, and it is this factor which affects so largely the nature of the vegetation indigenous to different areas, and the varied beauties which the student of nature will find almost anywhere in this Island of ours ; indeed, of all the influences which have contributed to make the world beautiful, that exerted by the flow of water is probably the most striking and the most conspicuous and universal in its effects.

Should you ever have the opportunity (as I have had) of making a general topographical survey of a district with an experienced geologist, do not hesitate to take it. You will find delight in observing the (apparently magical) skill with which he will identify the succession of permeable and impermeable strata merely by noting the nature of the vegetation, and trace from a line of springs the outcrop of a permeable bed overlying an impermeable one. Indeed no study will contribute more to make the wonders and beauties of nature apparent—and thus to provide unexpected pleasure in the observation of the most ordinary physical and natural phenomena—than that of hydro-geology.

The water engineer will, however, have to carry his investigations far beneath the superficial beauties of the landscape, and, having identified the surface conditions at the outcrop of the water-bearing strata, to trace the progress of the precious element in its adventurous career underground. Comparatively

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* Second part of a lecture delivered on February 24th, 1915, before the Birmingham University Engineering Society (affiliated to the Society of Engineers, Incorp.). The first part was published in our June number.

little practical experience will prove that the phrase "adventurous career" is by no means misapplied in the present case.

While presenting evidences of remarkable uniformity in its formation, the earth's crust is distinguished, like its surface, by its want of uniformity ; and this it is which provides intense interest in the one case as it provides entrancing beauty in the other. There is no water beneath the surface which has not found its way there by percolation from the surface, and every stream of underground water can be traced to the surface, as definitely as every surface spring can be traced to its source.

The next point of importance connected with underground water is that the flow through permeable strata is governed by the slope or configuration of the impermeable beds above and beneath ; thus in tracing the section of a water-bearing stratum, it is most necessary to trace also the relative depth, inclination and homogeneity of the strata forming as it were the bed of the underground stream and the roof of the underground reservoirs, as these govern the level at which water will be found, and that to which it will rise when tapped.

Now, varied as are the conditions provided by the juxtaposition of the various strata, much greater variety still is provided by the variable character of the permeable beds from which water is usually obtained.

The most prolific sources of underground water supplies in this country, are

1. The Chalk.
2. The New Red Sandstone (Bunter Beds).
3. The Oolitic Limestone.

and 4. The Lower Greensand.

They present great diversities in regard to the conditions most favourable to the finding of water. Thus, chalk is almost impervious as regards its bulk, and water can only be abstracted by tapping fissures. The fissures are, however, large and abundant in most cases, except where the chalk is overlaid by a great thickness of (London) clay. The New Red Sandstone is on the other hand characterised by bands of pebbles through which water will flow freely. Oolitic limestone is somewhat similar to chalk except that it is more freely fissured, and therefore more favourable as regards obtaining a good supply of water at any given point. The Greensand is, on the contrary, of a more homogeneous character and water can be drawn freely if a certain amount of sand is allowed to pass with the water. The many other less important water-bearing strata present similar varieties, and it will be seen that, in designing large works for the supply of towns, it is vitally important that the method of collecting the water should be adapted to the peculiar character of the beds from which it is to be obtained. (This

point is of course of less importance in dealing with small supplies to single houses or to public institutions.)

The design of underground works is therefore a matter requiring much consideration and, particularly, extensive experience, and I may here justify my reference to "Gravitation Schemes" as being of a comparatively simple character. In every case the engineer has a certain number of conditions presented to him, among which a certain proportion are unknown and subject to more or less reasoned speculation. Now, however speculative may be the conditions governing the water supplies in upland gathering grounds, those involved in problems of underground water are infinitely more so, and the proportion of unknown factors is enormously greater: nothing therefore but extended experience (including many failures) can qualify an engineer to advise on questions of underground water supply. At the same time no subject is more fascinating to one with sufficient energy, determination and patience to carry him through the initial difficulties and disappointments which are the essential preliminaries of a successful practice.

Broadly speaking underground waterworks may be classified as follows:—

1. Shallow wells for tapping subsoil water.
2. Deep wells for tapping deep-seated reservoirs.
3. Wells with artesian borings to tap deep-seated streams.

and 4. Borings (either with or without chambers or wells to take the pumps).

(1.) *Shallow wells for subsoil water.* In the first of these the greatest difficulty to be provided against is the pollution of the water, and it is important that the well should be made perfectly water-tight for such depth as may be necessary to filter out impurities drawn in at the surface. The water will then be unable to get access to the well until it has passed through a sufficient depth of the subsoil to filter it effectively. This depth will vary according to the nature of the pollution, the character of the subsoil, and the rate at which water is abstracted. In some cases water is collected in surface gravel beds by means of drain pipes laid with open joints, but unless the area drained by this method is carefully preserved from pollution at the surface, it is a dangerous system of collecting water intended for domestic use.

There are several methods of making wells watertight, the most efficient (and the most expensive) being to line them with cast iron cylinders, which can be cast in rings up to 4 ft. diameter, but beyond this size are best made in segments with vertical joints. The vertical flanges are of course useful and necessary in any case as stiffeners. Cast iron cylinders are,

however, more generally used in deep wells and their application will be more fully described under that head.

The more common method of making shallow wells watertight is to line the excavation with a single ring of brickwork (in some cases specially moulded bricks being employed) and to pack the space behind with concrete. The face of this ring is then rendered with cement mortar about 1 inch thick and another ring of brickwork is then built up as a protection to the mortar. As brickwork must be built *upwards*, it is necessary in such cases to suspend in the well a temporary ring or curb on which the brickwork is supported until the packing behind provides sufficient bond to prevent it slipping down the well. In cases where the sides of the excavation are liable to fall in, it is necessary to fix a temporary lining of timber, which is removed as the brickwork proceeds. It is also better to erect the brickwork in sections rather than to rely upon timbering for any great depth.

Watertight work can also be obtained by laying a two-brick ring in one operation with cement mortar joints and backing, but the former method is generally preferred.

2 & 3. *Deep wells* (*with or without Borings*). In deep wells the chief difficulties arise through the variations of strata passed through. Thus a narrow band of fine wet sand will make it almost impossible to carry out the lining in brickwork, indeed any sandy or loose strata will involve difficulties in supporting the excavation while brickwork is built up. In such cases cast iron or wrought iron cylinders are used, and these must be driven down from above. The tendency of the surrounding material to close in behind the cylinders will sooner or later make it impossible to force the cylinders down beyond a certain depth, and at that point, cylinders of smaller diameter must be inserted inside the upper section until in turn these become fast, when a further reduction of diameter must be made. Should a solid bed of clay be subsequently met with, it is possible to resume lining with brickwork, and in that case the diameter can be increased to provide facilities for fixing pumps and space for giving access thereto.

I have separated wells tapping underground reservoirs from those having borings carried down from the bottom, because they apply to different geological conditions. In the former case the water does not rise when tapped as it has no " artesian " head, and the well is merely carried down into a reservoir such as would exist where it was sunk wholly through the water-bearing stratum from which the supply is to be derived. In chalk it would probably be necessary to drive adits or headings longitudinally in order to secure any large quantity of water, as a well of any

ordinary dimensions would not be likely to intersect a sufficient area of fissures to collect any large volume of water.

In the second case (wells with borings) the well is merely constructed to enable the pumps to be fixed below the water level, and the water is tapped by means of a boring driven from the bottom. This arrangement is applicable only where the water is under an "artesian head," that is, when it is tapped below the "line of saturation," and therefore rises up the boring when the superincumbent impervious bed is perforated.

A striking example of this kind of well was carried out by me for the Lincoln Corporation ; the well was carried down in impervious clay to a depth of 1,500 ft., and at 1,560ft. the boring (which was ultimately carried to a depth of 2,020 ft.) tapped water, which immediately rose up the well until it overflowed at the surface.

4. *Borings.*—It will be realised that in sinking wells in water-bearing strata it is necessary to pump out the inflowing water continuously to enable the men to excavate the material and construct the lining. This frequently constitutes a large item of expense, and it is then necessary to consider the alternative of boring, a process not only less costly and quicker than well-sinking, but one which is carried out entirely from the surface, thus avoiding the risks of accident inseparable from work underground.

The head gear used in sinking the well and driving the boring at Lincoln already referred to is known as Mather & Platt's machine. The essential feature of this apparatus is the use of a flat hemp rope for suspending the boring chisel, and raising and lowering the "shell." This rope is wound on a drum which is operated by an engine fixed on the rear framework of the machine. The process of boring consists of two distinct operations ; the first is the reciprocation of the boring chisel, which was in this case 24 in. in diameter when the boring was at its greatest depth (2,020 ft.), and consisted of a circular disc of steel perforated with holes in which are bolted a number of steel chisels, the disc being suspended at the end of a steel rod or vertical shaft about 12 ft. long and from 5 in. to 6 in. diameter, on which a skeleton disc is fixed near the top to form a guide. During this operation the drum is fixed in a stationary position, and the rope is clamped to the frame of the machine so that the chisel will just reach the bottom of the boring. The rope is passed over a pulley fixed on the upper end of a ram working in a vertical steam cylinder so that the admission of steam to this causes the pulley to rise, carrying the rope and suspended chisel with it. When this has been raised a certain height (depending on the nature of the strata being bored through) the steam is released, and the weight of the chisel (this one weighed several tons) carries the rope, shaft and

tool to the bottom with a force proportional to the amount of "fall" allowed. This operation is continued for periods varying with the progress of the boring, that is, until sufficient material has been excavated to impede the working of the chisel.

The drum is then operated to wind the rope and chisel to the surface, the chisel is detached, and the "shell" substituted. This is merely a large steel cylinder fitted with a hinged bottom opening inwards. This is lowered to the bottom and reciprocated for a few minutes, after which it is drawn rapidly (that is, much more rapidly than the boring chisel) to the surface, and its contents discharged into wagons for removal to the tipping place. This is repeated until the foreman in charge is satisfied by the feel of the rope that the loose material has been removed, when the chisel is again lowered, and the cycle of operations is resumed as described.

Although this description applies to a boring of rather unusual dimensions, the process adopted is that in most common use for deep borings, except that the flat rope enables the chisel to be automatically revolved at each stroke, whereas when ordinary circular rope is used the tool has to be revolved by manual labour. For smaller borings steel rods are used in place of ropes, but these have to be lifted in sections, unscrewed, and slung aside every time the tool is raised for "shelling" out the debris, and replaced when the "shell" or chisel is lowered.

As the boring proceeds it is necessary to drive down steel (or in some cases cast-iron) tubes to prevent the sides from falling in, and as in the case of well cylinders, these will sooner or later become jammed by the closing in of the surrounding strata. When this occurs it is necessary to insert a line of tubes of smaller diameter, and in some cases a considerable number of such reductions is necessary before the full depth can be attained. As the work proceeds each separate line of tubes must be provided of the full depth of the boring, so that it can be forced down from the surface, but on the completion of the work each section of tubing can be cut off at such a point as will provide a lap of about 20 ft. in the next larger section. If, however, there is any risk of polluted water passing through the junction into the boring, the inner and smaller lining tubes must be left in for the full depth.

Pumping Machinery.—It will have been observed that, although my second division of Water Supply Schemes was headed "Surface and Underground Supplies," I have as yet said nothing about surface supplies. The reason is that works of this character involve no essential problems other than the design of the pumping machinery and the question of filtration (which I cannot deal with in the time at my disposal).

As the question of pumping machinery is in itself a distinct branch of mechanical engineering, and to that extent lies some-

what outside the sphere of the civil engineer, it is hardly possible for the water engineer with a general practice to master thoroughly all the details involved in the design and construction of boilers, engines, pumps and their accessories. The engineer in charge of a works where pumping machinery is in use must, however, devote his attention to at least the broader elements of the subject, and he will, by virtue of his responsibility for the economical upkeep of his plant, be compelled to master thoroughly the details of the machinery under his care. As, moreover, he will, at intervals, be called upon to advise as to the extension, removal, or improvement of the plant at his works, he must keep himself thoroughly up to date as regards the relative efficiency or other advantages or disadvantages of different designs of pumps and motors for operating them. The consulting engineer, having possibly no works under his constant supervision, must lose no opportunity of collecting experience and information as to the results obtained with various types of plant under different working conditions. For all alike it is extremely desirable that the early training should include service in the shops of a firm manufacturing pumping machinery, as by no other means can the mind be educated to that intuitive grasp of mechanical problems which is essential to secure *independence of judgement*. Without such training it is also very difficult, if not impossible, effectively to superintend work carried out by such firms, and, such inexperience must be paid for, directly or indirectly, by the employer or client.

As there is almost endless variety in the types of pumping plant in use for waterworks, it is out of the question for me to do more than briefly outline the main sub-divisions into which the subject may be classified.

Broadly these are :—

(1) Surface pumps (low and high lift.)
(2) Well pumps, and
(3) Borehole pumps.

and for motive power :—

(*a*) Steam Engines (direct acting or geared.)
(*b*) Internal Combustion Engines (gas or oil.)
(*c*) Electric Motors.
(*d*) Air Lift (including Compressing Plant.)
and (*e*) Water Wheels and Hydraulic Motors.

1. *Surface Pumps*. For low lifts and proportionately large deliveries, the single centrifugal pump is very convenient, mainly on account of the absence of valves and the high speed at which they are run, thus allowing them to be coupled to high speed motors without the interposition of gearing. It is, however,

rarely the case that waterworks can be supplied by low lifts, and the application of this type of pump is therefore very limited.

Another special pump suitable for low lifts is the " Humphrey" internal combustion pump of which a very striking example is at work at the new Chingford Reservoir of the Metropolitan Water Board. This is a combination of engine and pump in one piece without pistons, buckets, gearing or any close fitting parts whatever. It operates by a cycle similar to that known as the " Otto " cycle, that is (*a*) the explosion chamber is charged with the proper proportion of air and oil vapour drawn in (in this case by the movement of a body of water), (*b*) the mixture is compressed (in this case by the return movement of the water), (*c*) the explosion of the mixture expels the water and elevates it to the point of discharge, and (*d*), the explosion chamber is swept clear of the products of combustion (again, by the pendulum-like action of water.)

For high lifts the plunger pump is most suitable, as this lends itself to any variety of conditions both as regards space occupied, position (horizontal, vertical or inclined) and type of motive power. The term " surface pump " may be applied to any case where the pumping level of the water is within 25 ft. (vertically) of the surface, as under such circumstances the pump itself can be fixed on the ground level.

2. *Well Pumps.* — In three-throw bucket-and-plunger pumps, suitable for fixing in wells at depths of from 50 ft. to 100 ft. below the surface, the pumps are operated by steel rods carried in suitable guides fixed to the side of the well, the reciprocation being given by a crank shaft with three cranks set at an angle of 120° to one another. The delivery of water is thus almost constant throughout the revolution, and this type of pump is very popular on account of the absence of shock in the rising main due to this cause.

3. *Borehole Pumps.*—Where it is decided to dispense with a well, it is, of course necessary (unless the pumping level of the water is within 25 ft. of the surface) to fix the pump in the boring. This limits the design of the pump to two types, viz.—the single-acting bucket pump, and the " concertina pump " (double acting).

One modern development of borehole pumps must be briefly mentioned and that is the multiple-centrifugal pump. This consists of a series of centrifugal pumps revolving on a common axis or shaft. The water passed from the outlet of one to the inlet of the next acquires an increased pressure at each stage, and by this method, high speed engines or electric motors can be applied to this type of plant without the need for gearing of extravagant proportions.

Various types of motive power.—This subject is extremely fascinating because it involves so many points which interact upon one another and which, considered separately, may produce results altogether contrary to those which result from the combination of all. This may be best illustrated by a brief reference to the various types I have enumerated.

(*a*) *Steam Engines* are even yet the most reliable machines for driving pumps, and in large installations the fuel economy obtained with them compares favourably with that obtained with any other more modern system. In cases where, owing to the gradual falling off of the yield of water, it is desired to run the pumps at slow speeds, the steam-driven pump is the only one which will meet the case economically and efficiently.

(*b*) *Internal-Combustion Engines* offer the greatest attraction in regard to fuel economy and first cost, and for small works they must be considered as generally the most suitable. Gas Engines operated by independent producer-gas plants give remarkable results as regards fuel economy, and although this advantage is somewhat discounted by the stand-by losses and the cost of maintenance, experience has now proved the system to be very well adapted for small waterworks.

The oil engine has also proved a very convenient motive power for small rural works, as the supervision required is reduced to a minimum, but in recent years the invention and development of the Diesel engine has given this type of power an advantage over other internal-combustion engines. The fuel economy has been greatly increased, and the larger sizes of plants have given results which bid fair within a short time to exceed those obtained with every other type of plant. (The application of this system to marine propulsion will, no doubt, be known to all present). Nevertheless this, like every other internal-combustion engine, must be run at high speeds and for this reason, it is not applicable to the ordinary types of pump, except by means of elaborate systems of gearing, which by their cost, friction losses, and excessive wear and tear, largely discount the initial advantages offered by the engine.

(*c*) *Electric Motors* are, of course, often applied to pumps, but except with centrifugal pumps, their high speed involves the use of gearing, and unless electricity is available at very low cost, or other power is not available, electric motors are not often employed for pumping.

(*d*) *Air Lift Plant.* This is a very convenient method of raising water from deep borings, particularly for temporary purposes, such as testing the yield, or removing accumulated sand and debris. It has the advantage of dispensing with valves and working parts in the borehole. It is also convenient in cases where water has to be drawn from a number of borings

in the same neighbourhood, for a central power station can provide compressed air sufficient for all and so avoid the establishment of a separate works at each boring. It has, however, the disadvantage that the average fuel-cost is about three times that of any other type of pumping machinery, moreover the air pipe must be immersed to a depth below the pumping level almost equal to the height to which the water has to be lifted, thus the boring must (in many cases) be carried to a depth much greater than otherwise required.

(*e*) *Water Wheels and Hydraulic Motors* (including therein turbines) are occasionally convenient methods of operating pumps, particularly in cases where pumping stations are situated adjacent to large rivers. Examples can be seen at Reading, Windsor and Guildford, but this type of motor is better suited to countries where water power is more liberally provided by Nature than it is in the United Kingdom, and in such cases it is usually found more economical to utilize the water power for generating electricity, which in its turn can be applied to all industrial purposes with almost equal facility.

Conclusion.—It would have been very interesting to have considered many other important branches of the water engineer's work, such as the design and execution of the conduits or pipe lines conveying water from distant watersheds, and the varieties of modern practice in the design of service reservoirs in connection with which reinforced concrete now plays so important a part ; there is also a vast field for research in chemical analysis and bacteriological examination of water, the detection and prevention of pollution, the filtration and softening of water, and problems connected with the distribution of water supplies, the prevention of waste, and the supply of water for fire extinguishing, but I have thought it best to select a few more elementary problems and treat them in some detail rather than to cover more ground in a very summary manner. I shall, however, be content if what I have said is of sufficient interest to induce you to investigate these other matters for yourselves as opportunity offers.

THE UTILISATION OF SOLAR ENERGY.*

By A. S. E. Ackermann, B.Sc. (Engineering), A.C.G.I., M.Cons.E., A.M.Inst.C.E.

The author opened his paper with some statistics relating to the Sun, the chief of which are the following :—

Temperature : about 6000° Centigrade.

Specific gravity : 1·38 (Sp. gr. of the Earth 5·52, of granite 2·64.)

Diameter : 863,600 miles (about 100 times that of the Earth)

Surface (considered as a flat disc) : $58·575 \times 10^{10}$ sq. miles.

Energy emitted : 12,500 h.p. per sq. foot.

Energy received at the outer surface of the Earth's atmosphere : about 7,300 h.p. per acre.

The energy received at the surface of the Earth at noon on a clear day is about 70% (say 5,000 h.p. per acre) of the preceding amount, and is less in the morning and evening owing to the greater thickness of atmosphere through which the radiation has to pass.

The quantity of solar heat per unit area which arrives in unit time at the outer surface of our atmosphere is called the solar constant, and its value, as determined in 1913 by C. G. Abbot, of the Smithsonian Institution, after making 696 experiments in different parts of the globe, is 1·93 calories per sq. cm. per min. (=7·12 B.T.U. per square foot per minute.) Its value given by various experimenters between 1881 and 1909 was considerably higher, and this makes it all the more remarkable that John Ericsson, the engineer and inventor who spent some £20,000 on experiments with solar energy, when writing in 1876 a record of his life's work, gave the value of the solar constant as 7·11 B.T.U. per square foot per minute, saying that "it is not probable that future labours will change the result of our determination," and as shown above, his confidence was justified.

Solar radiation passes through the 93,000,000 miles (one million is 2,740 a day for a year) of space between the Sun and the Earth, the temperature of which is nearly absolute zero (*i.e.*, it is about — 263° C.), and only three-fifths of it produces any impression on the eye. It is not till the radiant energy impinges

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* Abstract of a paper (for which the Author was awarded a Silver Medal) read before the Royal Society of Arts, on April 28th, 1915. As the paper supplements the one read before our Society on April 6th, 1914, for which the President's Gold Medal was awarded to the Author, the Council consider that the publication of this abstract will be of interest to the members. The paper and the discussion thereon may be read in full in the *Journal of the Royal Society of Arts*, Vol. LXIII, No. 3,258, 30th April, 1915, pp. 538-65, price 6d. from that Society.

on some material body that it is converted into heat. The best body for causing such conversion is a dead-black one.

The absorption of solar energy by the atmosphere is about 20 per cent. greater in summer than in winter. This may be due to there being a larger total quantity of water vapour in the atmosphere in summer than in winter. It has long been known that the greater the humidity of the atmosphere the greater the amount of heat stopped by it ; but the author believes that his experiments in Egypt in 1913, with the Shuman-Boys sun-power plant, were the first which determined the quantitative effect of humidity, especially on so large a scale.*

Only a fraction of the available energy of the sun's heat can be utilized, and the following comparisons are instructive :—

Source of Heat.	Converted into Mechanical power by	Percentage of Heat Value utilised under best conditions.
Good Coal ...	Boiler and Steam Engine	11·5%
Gas	Gas Engine	25·5%
Oil	Diesel oil Engine	31·0%
Sun	Shuman-Boys Plant	4·32%

The low thermal efficiency of the Shuman-Boys plant may be accounted for by the low steam pressure and the fact that the best efficiency of the sun-heat absorber was only 40·1% compared with 75 per cent. for the best coal-fired boiler. But it has taken boilermakers many years to attain this efficiency, so that 40·1 per cent. is not a bad result when the small number of sun-boilers that have been made is taken into account. Thermal efficiencies of engines are materially affected by the heat-fall of the steam, just as the efficiencies of water turbines are affected by the height of the water-fall. The larger the fall in either case the better the efficiency.

The early experimenters with solar energy include Roger Bacon, an English Franciscan monk (1214–1294) ; Solomon de Caux, a French engineer (1576–1626), who invented and described in 1615 the first machine for raising water by solar heat and the expansion of air ; Buffon, the celebrated French naturalist (1707–1788); Ducarla ; H. B. de Saussure, the Swiss geologist, physicist and naturalist (1740-1799), and Sir John Herschel, F.R.S. (1792–1871).

The latter, in 1837, experimented with " a small mahogany box, blackened inside, covered with window-glass fitted to size,

* Trans. Soc. of Engrs. (Incorp.), Vol. V. (1914), Fig. 13, (facing p. 112).

but without putty, and simply exposed perpendicularly to the sun's rays," established under an external frame of wood well sanded up at the sides, and protected by a sheet of window-glass (in addition to that of the box within). The temperatures attained in December, 1837, ranged from 207° to 240° Fahr., and "some amusing experiments were made by exposing eggs, fruit, meat (December 21st, 1837, *et seq.*), all of which, after a moderate length of exposure, were found perfectly cooked."

Sir John determined the solar constant by means of a tinned iron vessel $3\frac{3}{4}$ ins. diameter and 2·4 ins. high, filled with inked water, upon which he allowed the nearly vertical rays of the sun to play through a 3·024 ins. diameter hole for ten minutes and noted the rise in temperature, of course allowing for cooling losses. The mean of six experiments, made between December 23rd, 1836, and January 9th, 1837, inclusive, gave a rise of 0·38° F. per minute, the quantity of water being 4,638 grains. Allowing for the obliquity of the Sun's rays, the mean area of the normal cross-section of the beam of sunlight was 7·01 sq. ins. From these particulars we are able to calculate that Herschel's value of the solar radiation reaching the Earth's surface was 1·38 calories sq. cm. min., while if we assume the coefficient of atmospheric transmission to have been 0·70, his value of the solar constant was 1·98, agreeing well with 1·93, the value now accepted as correct. From these experiments he deduced that a cylindrical rod of ice, 45·3 miles in diameter, and of indefinite length, continually darted into the sun with the velocity of light (186,000 miles per second), would barely suffice to employ the whole radiant heat for its fusion, without at all reducing the temperature of the sun.

Almost contemporaneous with the work of Herschel was that of Mons. C. S. M. Pouillet, a record of which, on the determination of the solar constant, appears in *Comptes Rendus*, Vol. VII, 1838, pp. 24-65. His value of the solar constant was 1·763 calories sq. cm. min.

Carl Güntner was at work experimenting with reflectors in Laibach (Austria) in 1854, and in 1873 he exhibited one at the Vienna Exposition, described in the *Scientific American Supplement* of May 26th, 1906, pp. 25,409–25,412.*

Günter says: "From these experiments it has been deduced that the amount of heat given off per square foot per minute is about = 1·3 (major) calories (= 1·4 minor calories sq. cm. min.).

The work of August Mouchot in connection with the utilisation of solar energy is recorded in his book, entitled "La Chaleur solaire et les Applications industrielles," second edition, 1879; but, as with other workers in this field, he gives extremely

* Quoted in the paper from which this abstract has been made.

meagre information as to results of experiments. Mouchot started his solar work in 1860, and took out his first patent, No. 48,622, on March 4th, 1861.

In August, 1866, the Emperor Napoleon III. of France saw Mouchot's first solar engine at work in Paris, and in 1872 Mouchot (with the monetary assistance of the French Government) constructed another sun-boiler in the shape of a truncated cone of copper, coated inside with very thin silver-leaf. At the central axis of the cone was a blackened copper boiler terminating in a hemispherical cap and surrounded by a glass cover. The greater diameter of the reflector was 2·6 metres and the lesser 1 metre, and it was 80 centimetres in height, giving 4 sq. metres of reflecting surface or of insolation.

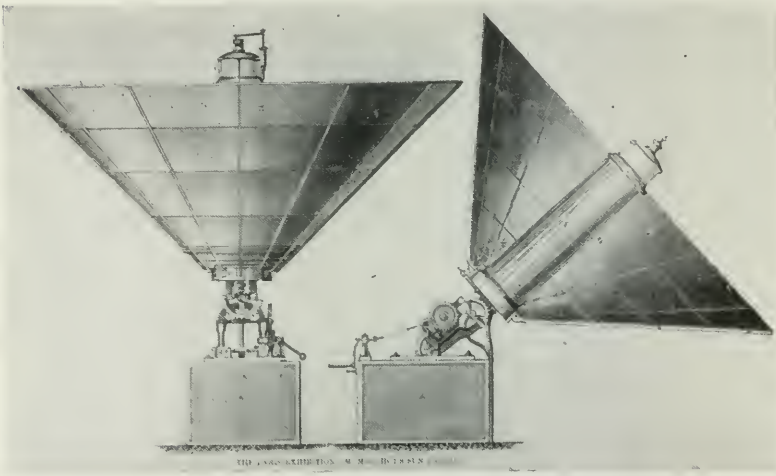

FIG. 1.—MOUCHOT'S MULTIPLE-TUBE SUN-HEAT ABSORBER, OF 1878.

"The boiler proper of the Tours solar engine consists of two concentric bells of copper, the larger one, which alone is visible, having the same height as the mirror, *i.e.*, 80 centimetres, and the smaller or inner one 50 centimetres ; their respective diameters are 28 and 22 centimetres. The thickness of the metal is only 3 millimetres. The feed-water lies between the two envelopes, forming an annular envelope 3 centimetres in thickness. Thus the volume of liquid is 20 litres, and the steam-chamber has a capacity of 10 litres. The inner envelope is empty. Into it pass the steam-pipe and the feed-pipe of the boiler. To the steam-pipe are attached the gauge and the safety-valve. The bell-glass covering the boiler is 85 centimetres high, 40 centimetres in diameter, and 5 millimetres in thickness. There is

everywhere a space of 5 centimetres between its walls and those of the boiler, and this space is filled with a layer of very hot air."

Mechanism was provided whereby the reflector was adjusted by hand to follow the movement of the sun. In the most favourable conditions the apparatus vaporized 5 litres of water per hour, equal to a steam production of 140 litres per minute or half a horse power. The steam was used to work a pumping engine. In 1878 Mouchot used a boiler made of many tubes placed side by side, and having a capacity of 100 litres (70 for water and 30 for steam).

Mouchot seems to have been the only inventor of a solar plant, with the exception of Shuman, who has had his apparatus tested by independent engineers. The following refers to Mouchot's plant. In *Comptes Rendus*, Vol. XCIV., 1882, pp. 943-5, Mons. A. Crova reports that: "The Minister of Public Works appointed two Commissions, one at Constantine and the other at Montpellier, to make experiments with two identical mirrors of 5·22 square metres in section normal to the sun's rays, and to evaluate their practical utility." Nine hundred and thirty observations extending over 176 days were made by the Commission of Montpellier, but unfortunately their report is in such a form that the author has not been able to interpret the results recorded therein.

Next came that versatile engineer and successful inventor, John Ericsson, a Swede by birth and an American by adoption. He made an immense number of experiments, extending over twenty years, with costly apparatus, to determine the solar constant, and later on made apparatus for the practical utilisation of solar radiation. All these experiments were made at his own expense, and he tells us they cost him £20,000, and having done all this work the conclusion he arrived at was: "The fact is, however, that although the heat is obtained for nothing, so extensive, costly, and complex is the concentration apparatus, that solar steam is many times more costly than steam produced by burning coal." (Letter dated September 21st, 1878, to R. B. Forbes.) His remarkably accurate determination of the solar constant has been referred to; but he was not so happy in deducing the temperature of the sun, which he made to be 723,000° C., the present accepted result being only 6,000° C.

He tried hot-air engines as well as steam engines for utilising solar energy, and claimed that the steam engine which he constructed in New York for this purpose in 1870 was the first one driven by the direct agency of solar radiation. The diameter of its cylinder was 4½ ins. He afterwards modified his solar hot-air engine so that it might be used as a small pumping engine, using gas as its heat supply. "The profits upon this chip from his workshop are already estimated at several times the amount

of the £20,000 expended by Ericsson upon the solar investigations leading up to this invention" (Vol. II, p. 275 of his "Life," by W. C. Church). Mouchot claimed, apparently correctly, that his engine was the first, and Ericsson admits that, "Some time previous to 1870, Mouchot made a small model engine, a mere toy, actuated by steam generated on the plan of accumulation by glass bells. . . . ."

Ericsson gives full details of all his apparatus for determining the solar constant in the record of his life's work, entitled, "Contributions to the Centennial Exhibition," New York, 1876; but unfortunately he did not describe in detail therein the solar boilers, although from the particulars he gives its efficiency appears to have been 72·5%, which is remarkably high.

In 1872 Ericsson built his hot-air solar engine, which had a reflector the shape of which was approximately a portion of a sphere, and which concentrated the solar radiation on to one end of the cylinder. The power of both these engines was evidently very small. On July 9th, 1875, Ericsson wrote that he had up to that time constructed and started seven sun motors. Ericsson wrote in *Nature* of January 3rd, 1884, an illustrated article describing another of his sun motors which he erected in New York in 1883, in spite of his opinion as to the cost of solar steam (previously quoted) expressed in 1878. His description was as follows: "Referring to the illustration (Fig. 2), it will be seen that the trough, 11ft. long and 16ft. broad, including a parallel opening in the bottom 12 ins. wide, is sustained by a light truss attached to each end, the heater being supported by vertical plates secured to the truss. The heater is $6\frac{1}{4}$ ins. in diameter, 11 ft. long, exposing $130 \times 9 \cdot 8 = 1{,}274$ superficial inches to the action of the reflected solar rays. The reflecting plates (of flat window glass, silvered underneath), each 3 ins. wide and 26 ins. long, intercept a sunbeam of $130 \times 180 = 23{,}400$ square inches section. The trough is supported by a central pivot, round which it revolves. The change of inclination is effected by means of a horizontal axle—concealed by the trough—the entire mass being so accurately balanced that a pull of 5 lb. applied at the extremity enables a person to change the inclination or cause the whole to revolve. A single revolution of the motive engine develops more power than is needed to turn the trough, and regulates its inclination so as to face the sun during a day's operation.

"The motor shown by the illustration is a steam engine, the working cylinder being 6 ins. in diameter, with 8 ins. stroke. The average speed of the engine during the trials last summer was 120 turns per minute, the absolute pressure on the working piston being 35 lb. per square inch. The steam was worked expansively in the ratio of 1 to 3, with a nearly perfect vacuum

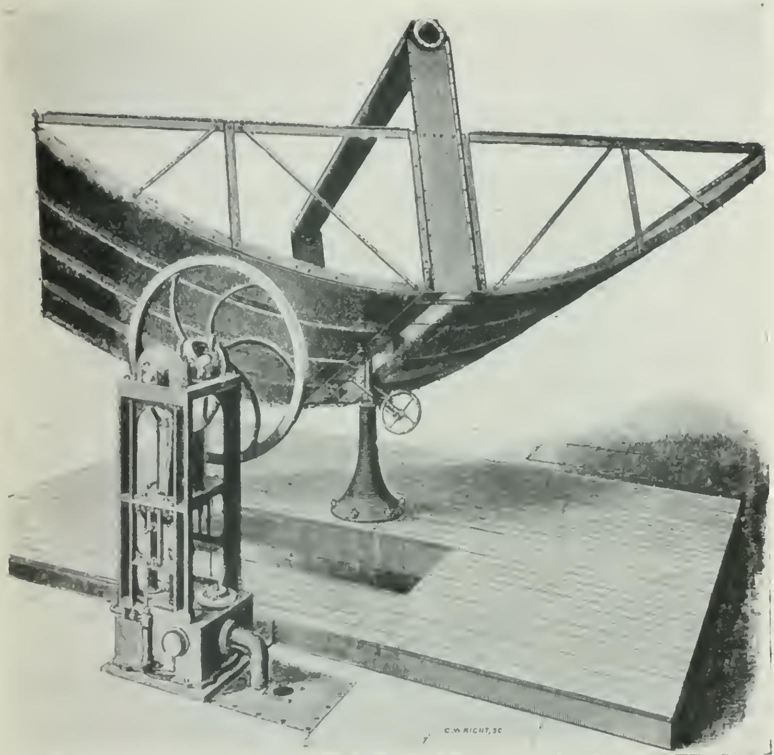

FIG. 2.—ERICSSON'S SUN-POWER PLANT OF 1883.

kept up in the condenser enclosed in the pedestal which supports the engine frame."

From the particulars given it is easily calculated that the "concentration" of this absorber was 9.

The Rev. C. H. Pope, in his book entitled "Solar Heat," (2nd edn., 1906), tells us he started his experiments (which do not appear to have included the conversion of solar radiation into mechanical energy) in 1875. He used a modification of Mouchot's truncated cone reflector formed of many plane mirrors—the plan adopted about the same time by W. Adams, Deputy Registrar, High Court, Bombay, who seems to be the sole Englishman who has worked on the practical side of the problem of the utilisation of solar energy. The work of the latter was done in India, and is recorded in his interesting book "Solar Heat" (Bombay, 1878).

In two particulars Adams was much at fault : (1) in believing that the solar rays which reach the earth are not practically parallel, and this in spite of the opposite opinions of the many physicists whom he quotes, and (2) in believing that the temperature attained at the focus of a lens or mirror is directly proportional to the concentration of the rays. As a consequence, he stated that if a lens 85 ft. 4 ins. in diameter concentrated the radiation on to a circle ½ in. in diameter the temperature would be 73,400,320° F. This is equal to 40,780,000° C., while the temperature of the sun itself is only 6,000° C., and no amount of such concentration could produce a temperature in excess of this. This error on the part of Adams and Pope seems to be due to a confusion of " temperature " with " quantity of heat."

His experiments were all made with plane or flat glass mirrors, the use of which he strongly advocated in preference to curved metal ones such as Mouchot used. One of his boilers was of copper $\frac{1}{16}$in. thick, 16 ins. diameter, 2 ft. 7 ins. high, and held 9 gallons of water, which boiled in 30 mins. and evaporated 3¾ gallons in an hour. His next boiler was also of copper ¼ in. thick, and of the same design and external dimensions as Mouchot's, but with a water space between the inner and outer shells of 3 ins., instead of 3 cm., and containing 12 gallons of water as compared with Mouchot's 4½ gallons. Adams wrote, " When this boiler had been properly fitted up by professional fitters, a steam pump was hired, said to be of 2½ h.p., and it was connected with the steam-pipe. At 7.30 a.m. fire was opened on the boiler from the whole battery of sixteen mirrors, at a range of 20 ft., the boiler containing 12 gallons. At 7.45, *i.e.*, a quarter of an hour, there was a pressure of about 2 lb., and at 8.30 a.m. 55 lb. The steam was then turned into the cylinder of the pump, and the pump was kept working at a uniform pressure of about 30 lb. to the square inch.

" This pump, the first steam engine ever worked in India by solar heat, was kept going daily, for a fortnight, in the compound of my bungalow at Middle Colaba, in Bombay, and the public was invited, by a notification in the daily papers, to witness the experiments."

Adams also made a solar cooker, the reflector of which was formed of eight sheets of plane glass arranged so as to form a hollow truncated octagonal pyramid, 2 ft. 4 ins. in diameter at the larger end. The food was placed in a cylindrical copper vessel, at the axis, covered with an octagonal glass shade. Both he and Mouchot found (p. 98) that animal fat " when exposed to the direct or reflected rays of the sun was converted into butyric acid, a substance having such an offensive odour and taste as to render the roast unpalatable. Mouchot then discovered that a sheet of red, pink, or yellow transparent glass,

interposed between the roast and the reflector, had the effect of preventing this fermentation, as those colours have the curious property of absorbing, neutralising, or eliminating the rays by which it is caused." Taking into account that he spent little money on his experiments, and that he did the whole of his solar work in eighteen months, it will be admitted his was a

FIG. 3.—ADAMS'S SOLAR COOKER, 1876.

most creditable piece of work, especially as he was neither an engineer nor a physicist. He was awarded the gold medal of the Sassoon Institute of Bombay for his essay on "The Utilisation of Solar Heat," submitted in March, 1878.

In *Comptes Rendus*, Vol. XCI, 1880, pp. 388-9, Mons. Abel Pifre claims an efficiency of 80 per cent. for his apparatus when, he says, he obtained a rate of absorption of 1·21 calories sq. cm. min. If such a rate were obtained, we now know it would mean an efficiency of 89·7 per cent., which is improbable. Pifre used a parabolic reflector (instead of a truncated cone), and reduced the surface of the boiler, thus increasing the concentration. The capacity of his boiler was 11 gallons, and he collected 100 sq. ft. of solar radiation, so the diameter of his reflector was about 11 ft. 4 ins. He used a rotary pump, and raised 99 litres of water 3 metres in 14 minutes, which is equivalent to 0·065 h.p. He ran a printing press with his sun-power plant, and claimed that if he had collected 216 sq. ft. of radiation he could have produced 1 h.p., which is quite likely.

Next in order we have Langley's work, which consisted of many experiments to determine the value of the solar constant, the value of which he gave as 3·0 calories sq. cm. min.

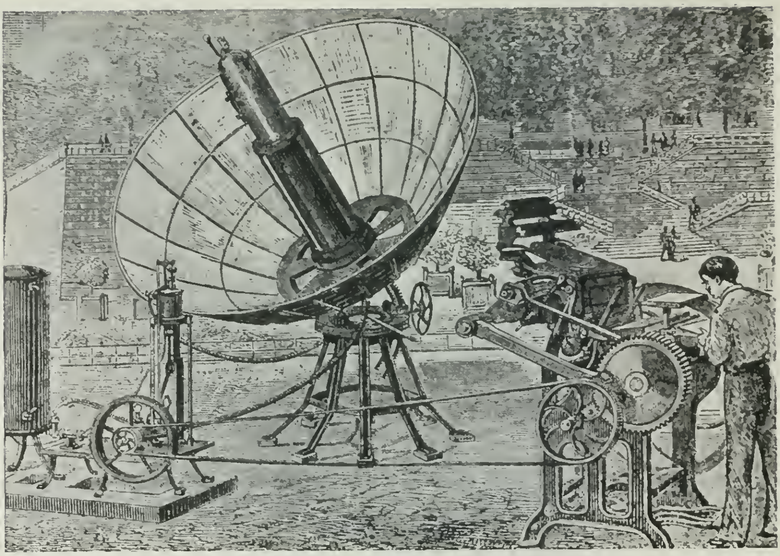

FIG. 4.—PIFRE'S SUN-POWER PLANT, OF 1878, DRIVING A PRINTING PRESS.

Langley experimented with de Saussure's "hot box," and was the leader of the expedition to Mount Whitney, where some of his best work was done. He gave a preliminary account of this trip in *Nature* of August 3rd, 1882, pp. 314-17, and a full record of it under the title "Researches on Solar Heat" in the U.S.A. War Department, Papers of the Signal Service, XV., 1884. He also referred to it in "The New Astronomy" (1900).

In *Nature* (p. 315) he said: "As we still slowly ascended, and the surface temperature of the soil fell to the freezing-point, the solar radiation became intenser, and many of the party presented an appearance as of severe burns from an actual fire, while near the summit the temperature in a copper vessel, over which were laid two sheets of plain window glass, rose above the boiling-point, and it was certain that we could boil water by the direct solar rays in such a vessel among snowfields."

In Vol. LXXIII. of the *Proceedings Inst. C.E.*, 1883, p. 284, is described a plant designed by J. Harding, M.Inst.C.E., for distilling water by solar radiation. The total cost of the plant, including pumps, windmills and tanks, was $50,000, or 1*s*. 6*d*. per square foot of glass.

(To be concluded.)

THE UTILISATION OF SOLAR ENERGY.*

By A. S. E. Ackermann, B.Sc. (Engineering), A.C.G.I., M.Cons.E., A.M.Inst.C.E.

(Continued.)

It is not clear when the solar energy problem first engaged the attention of C. L. A. Tellier, a French refrigerating engineer; but in 1889 he published his book, "Elevation des Eaux par la Chaleur Atmosphérique," in which he gave many drawings and details, and a very full description of his plant. He may have been the first to use the lamellar boiler, but the U.S. Patent No. 230,323, of July 20th, 1880, of MM. Molera and Cebrian, shows that they proposed this form of boiler. The dimensions of each section of Tellier's boiler were 3·50 m. × 1·12 m. They were made of thin plates of iron, so riveted together as to give them a quilted formation. They were filled with ammonium hydrate, which, he says, when heated by the sun produced gaseous ammonia at a pressure of "several atmospheres." The ammonia gas was used in a small vertical engine, and was then liquefied in a condenser and used again. The boilers were fixed in a sloping position so as to "face the sun," and two somewhat fanciful illustrations show them used as roofs of verandahs. The boilers were insulated on their lower or shade sides to prevent loss of heat, and were placed in shallow boxes with only one layer of glass to form the cover. He experimented with different coloured glass, and found, as might be expected, that colourless glass gave the best results. He also gave complete details of his invention as applied to the manufacture of ice. With so much detail it is disappointing that the author could not find the results of a single experiment with the plant. In fact, he is not sure whether Tellier ever constructed one.

In his work "La Conquête Pacifique de l'Afrique Occidentale" (1890), Tellier discussed social and economical questions, and showed how improvements might be made by rendering the deserts of Africa productive by means of his sun-power plants.

A. G. Eneas, in the United States, used the popular truncated cone-shaped reflector, collecting about 700 sq. ft. of solar radiation. The weight of the reflector was 8,300 lb.

The boiler was formed of two concentric steel tubes, the two together being encased in two glass tubes with an air space between them, and another air space between the inner glass one and the outer steel tube. The water circulated up between

* See Footnote August issue of JOURNAL, p. 177.

the inner and outer steel tubes and down the inner tube. The boiler was placed at the axis of the cone. Its length was 13 ft. 6 ins., its water capacity 834 lb. (13·4 cubic ft.), and steam space 8 cubic ft. Hence the diameter of the outer tube appears to have been 1 ft. 2 ins., and the concentration of radiation 13·4, *i.e.*, 13·4 sq. ft. of sunshine were concentrated on each square foot of the external surface of the boiler.

Eneas refers to his " nine different types of large reflectors," and found that he obtained better results when he concentrated the reflected rays " on two parts of the boiler instead of its entire length, as in the Pasadena machine." The unexposed portions of the boiler then appear to have been lagged. Eneas said, " I find 3·71 B.T.U. per sq. ft. per min. as the greatest amount of heat obtainable during the trial runs." This gives a maximum efficiency of 74·5 per cent. He also stated that, " the interposition of a single thin glass plate in a beam of sunlight diminishes the intensity about 15 per cent.

Abbot found the following percentages of heat were transmitted through sheets of glass, each from 1·5 to 2 mm. thick. In one set of experiments the glass was normal to the rays, and in the other at an angle of 45°.

No. of Sheets of Glass.	Percentage transmission.	
	Rays normal to glass.	Rays at 45° to glass.
1	86·5	85·0
2	74·5	71·8
3	63·5	60·0
4	53·3	49·0

The sun-power plant known as the Pasadena* one was described and illustrated in the August, 1901, issue of *Cassier's Magazine* by Professor R. H. Thurston, LL.D., D.E., and on p. 103 of *The Railway and Engineering Review* of February 23rd, 1901. It is stated to have been designed by, and erected at the expense of, " a party of Boston inventors whose names have not been made public." It consisted of a truncated cone reflector, 33 ft. 6 ins. in diameter at the larger end and 15 ft. diameter at the smaller, with a boiler 13 ft. 6 ins. long, having a capacity of 100 gallons (U.S.A.) plus 8 cubic ft. of steam space.

The article in *The Railway and Engineering Review* states : " According to newspaper accounts, the all-day average work

* There appear to have been several plants erected at Pasadena by different experimenters. Probably Eneas designed the plant above described.

performed by the engine is 1,400 gallons (U.S.A.) of water lifted 12 ft. per minute, which is at the rate of 4 h.p." It is more nearly $4\frac{1}{4}$ h.p., thus this plant required 150 sq. ft. of radiation per horse-power, and the concentration appears to have been 13·4.

The Pasadena plant is said to have cost £1,000, and Willsie, writing of it in 1909, says it was "the largest and strongest of the mirror type of solar motor ever built."

H. E. Willsie and John Boyle, Jun., started their work in America in 1902. The method they adopted was to let the

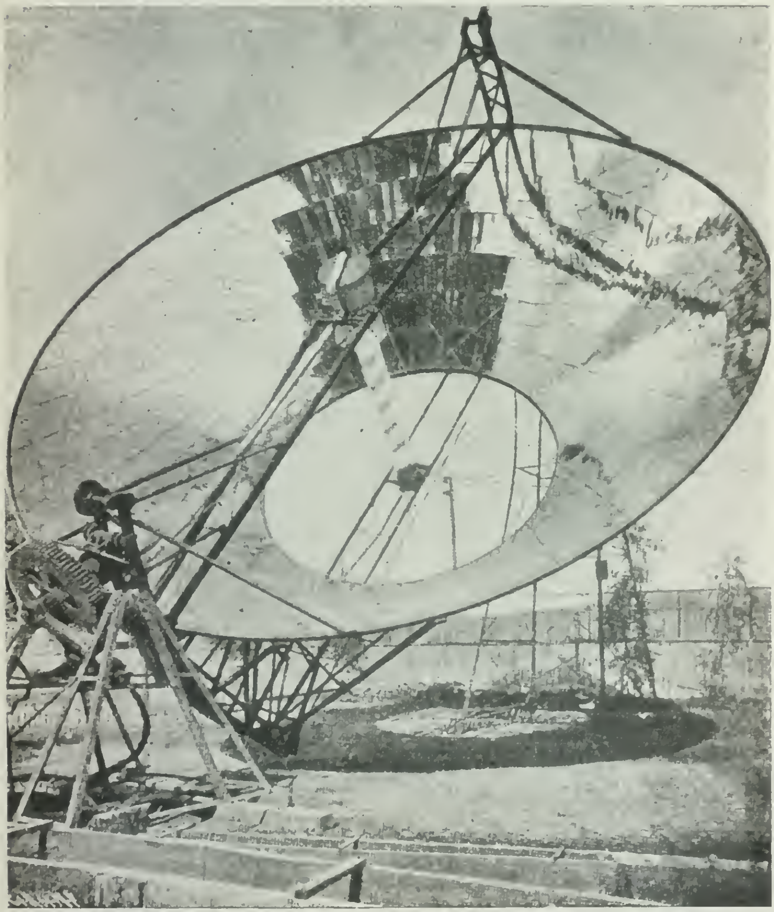

FIG. 5.—THE PASADENA SUN-HEAT ABSORBER, OF 1901.

solar radiation pass through glass and heat water, which in turn was used to vaporise some volatile fluid such as ammonium hydrate, ether, or sulphur dioxide, the vapour being used to drive an engine.

Willsie thinks he was the first to propose this two-fluid method for the utilisation of solar energy, and, so far as the author knows, his claim is correct. Their first sun-heat absorber was built at Olney, Illinois, U.S.A., and consisted of " a shallow wooden tank tightly covered with a double layer of window glass. The sides and bottom were insulated by enclosed air spaces filled with hay. The tank was lined with tar paper, well pitched to hold water to the depth of 3 ins. Although the weather was cold and raw, even for October, with occasional clouds, the thermometer in the water showed temperatures higher than were needed to operate a sulphur dioxide engine.

" The next solar heater was built at Hardyville, Arizona. Sand was used for insulation, and an estimate showed that 50 per cent. of the heat reaching the glass was absorbed into the water. In the spring of 1904 a complete sun-power plant was built at St. Louis. In this installation a 6 h.p. engine was operated by ammonia. The heater consisted of a shallow wooden basin coated with asphalt and divided by strips into troughs. It was covered by two layers of window-glass and insulated at the sides and bottom by double air spaces. Each trough of the heater formed a compartment. The troughs were inclined so that a thin layer of water flowed from one trough to the next. In this heater were collected and absorbed into the water from the sun's rays 211,500 heat units per hour at noon, or 377 heat units per hour per square foot of glass exposed to the sun. As, according to accepted solar observations, about 440* heat units per hour reached a square foot of glass, this heater was showing the surprising efficiency of 85 per cent., and collecting nearly twice as much solar heat per square foot per hour as did the apparatus of Ericsson. Of the lost heat I estimated that 40 heat units were reflected and absorbed by the glass and that 23 heat units were radiated. On cloudy days the water could be heated by burning fuel.

" It was then decided to build a sun-power plant on the desert, and some land about a mile from the Needles, Cal., was purchased for a site." This Needles plant used sulphur dioxide, and its results decided them to build a larger plant, which Willsie speaks of as their third sun-power plant, and describes as follows : " A 20 h.p. slide-valve engine was connected to an open-air

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* No, only 299. Note.—$0{\cdot}70 \times 1{\cdot}93 = 1{\cdot}351$ calories sq. cm. min. $= 299$ B.T.U. sq. ft. hr.

water-drip condenser and to a fire-tube boiler 22 ins. × 19 ft. having fifty-two 1 in. tubes. The solar-heated liquid flowed through the tubes, giving up its heat to the sulphur dioxide within the boiler. Boiler pressures of over 200 lb. were easily obtained. The engine operated a centrifugal pump, lifting water from a well 43 ft. deep (*sic*), and also a compressor, in addition to two circulating pumps."

Their fourth plant was a rebuilding of the third, and they tried the expedient of covering the heat-absorbing water with a layer of oil, but the results were not so good as when a heat-absorbing liquid (water, or oil, or a solution of chloride of calcium) was rapidly circulated in a thin layer. The sun-heat absorber for this plant was in two sections, one covered with one layer of glass and one with two layers, and both on a slope, the liquid running from the first to the second, and its temperature in the two sections being 150° F. and 180° F. respectively. The liquid at 180° F. was distributed over a "heat-exchanger" consisting of horizontal pipes about 3 ins. in diameter arranged in a vertical plane, something like an air condenser. The pipes contained sulphur dioxide, and the heat-absorbing liquid lost about 100° F. in its descent. The cooled liquid was returned to the two sections of the absorber to be reheated. The heat exchanger was enclosed in a glass-covered shed. Willsie says: "The engine used in this experiment was a vertical automatic cut-off, which at times, with a boiler pressure of 215 lb., probably developed 15 h.p. The two-heater sections exposed an area of about 1,000 sq. ft. to the sun, but as the heat was taken from storage and not directly from the heater, it is not fair to assume the above proportion of heater surface to horse-power developed.

"The condenser consisted of six stacks of horizontal pipes, twelve pipes to the stack. The cooling water, pumped from a well 43 ft. deep, had a temperature of 75° F. Only enough water was allowed to drip over the pipes to keep them wet, and so great was the evaporation in the dry desert breeze that the cooling water left the lower pipes at 64°. By using the cooling water over and over, the condenser gave very satisfactory results. A shade of arrowweed, a straight willow-like shrub abundant along the Colorado River, kept the sunshine from the condenser pipes and permitted a good air circulation."

Willsie estimated the cost of his sun-power plant, complete with engine, at £33 12*s*. per h.p.

With regard to Willsie's results, it is to be noted that 377 B.T.U. per hour means an efficiency of $\frac{377 \times 100}{60 \times 0{\cdot}70 \times 7{\cdot}12} =$ 126 per cent.; for we now know that a maximum of only about 299 B.T.U. per square foot per hour penetrate the atmosphere.

The author agrees with the 50 per cent. efficiency given a little earlier by Willsie.*

The work of MM. G. Millochau and Ch. Féry was started in 1906 to determine the solar constant and the temperature of the sun. Their work is recorded in *Comptes Rendus* for 1906 and 1908, and in the *Revue Scientifique* of September 7th, 1907. They give the absolute temperature of the sun as 6,042° C., and the value of the solar constant as 2·38 calories sq. cm. min. This latter value was the result of experiments they made on the summit of Mont Blanc in 1908.

The article in the *Revue Scientifique* of September 7th, 1907, is by Millochau, and in it he gives the following list of experimenters and the results of their determination of the solar constant, after reading which some may consider the word *constant* a misnomer :—

Pouillet	1837	1·793
Forbes	1842	2·82
O'Hagen...	1863	1·9
Voille	1875	2·28 to 2·37
Langley	1884	3·068
Savelief	1889	3·47
Pertner	1889	3·05 to 3·28
Angerstrom	1890	4·00
Hansky	1905	3·29
To these may be added :—		
Herschel	1837	1·98
Ericsson	1876	1·93
Millochau and Féry ...	1907	2·38
Abbot	1913	1·93

In spite of this history of comparative failures, the author is of opinion that the problem of the utilisation of solar energy is well worthy of the attention of engineers, for even now it is very nearly a solved problem where there is plenty of sunshine and coal costs £3 10*s*. a ton. It is fortunate that where coal is dear sunshine is often plentiful, and it is to be remembered that coal will gradually get dearer while the cost of manufacture of sun-power plants should decrease. Sun-power plants are admirably suitable for pumping in connection with irrigation, for where there is most sunshine there is need for most irrigation, and the slight variation in the quantity of water pumped throughout the day does not matter. Also, when temporarily there is no sunshine (owing to clouds), probably little or no irrigation is required.

* Here followed a short account of the work of Frank Shuman, which was fully dealt with in the author's earlier paper, and is therefore omitted from this abstract.

APPENDIXES.

The paper had four appendixes as follows :—

Appendix I. showed that for the Shuman-Boys absorber at Meadi, Egypt, with the boilers naked—*i.e.*, not covered with clear glass to prevent loss of heat by conduction—the *solar heat not used* amounted on the average to 8·68 B.Th.U. per hour per sq. ft. of boiler surface per 1° Fahr. difference between the temperature of the boiler and that of the air, the maximum variation being 5·5 below the mean to 5·1 above it. When the boilers were covered, this quantity was not constant.

Appendix II. dealt with the theoretical thermal efficiency of a solar heat absorber, and the author derived an equation for the efficiency of the absorber, as below

$$\eta = \frac{Dsa - pk\,(T^4 - \tfrac{2}{3}\,A^4) - (1 - r)\,Dsa}{Dsa}$$

Where D is the width in feet of the reflector.

- p ,, perimeter in feet of the boiler.
- r ,, efficiency of silvered glass as a reflector of heat.
- s ,, solar constant in B.T.U. per square foot per min. $=7 \cdot 12$.
- a ,, coefficient of atmospheric transmission.
- T ,, absolute temperature in degrees F. of the boiler.
- A ,, absolute temperature in degrees F. of the reflectors.

The temperature A was found to be about 9° F. above the shade temperature of the atmosphere.

The efficiencies thus calculated were compared with those obtained by experiment and shown to be rather higher.

Appendix III demonstrated that the best commercial result (or over-all efficiency) obtained from a solar heat absorber and engine, did not necessarily correspond with the maximum thermal efficiency of the absorber alone.

The equation to the overall efficiency of the plant is

$$\eta_{\circ} = \frac{\{Dsa - pk\,(T^4 - \tfrac{2}{3}\,A^4) - (1 - r)\,Dsa\}\ \ (T - 568)}{Dsa\,T}$$

where T is the absolute temperature of the steam and 568 the absolute temperature in degrees Fahr. of the condenser (taken as constant), the other symbols having the same meanings as in the equation given in Appendix II. Assuming the mirrors to have a temperature of 100° Fahr. and inserting the values of the other quantities (except T)

$$\eta_0 = 0 \cdot 71 - 404 \, T^{-1} + 9 \cdot 45 \times 10^{-10} T^3 - 1 \cdot 664 \times 10^{-12} T^4$$

Differentiating this equation with regard to T, and equating the result to 0, we obtain the value of T, which gives the maximum over-all efficiency under the given conditions.

This being done, we find T = (231 + 461)° F., corresponding to a steam pressure of 21 lb. sq. in. abs. Inserting this value of T in the equation just given, we find the *theoretical* maximum over-all efficiency of the Meadi absorber, combined with a Carnot engine, is 5·9 per cent., while the *actual* maximum was 4·32 per cent. The relative efficiency was thus 73·2 per cent. This means that we obtained nearly $\frac{3}{4}$ of the b.h.p. theoretically possible under the stated conditions.

Instead of differentiating the equation to *n*, we may insert various values of T, and thus calculate the corresponding values of η_0 and plot the results. The value of T which gives the maximum commercial economy is then readily seen by in-

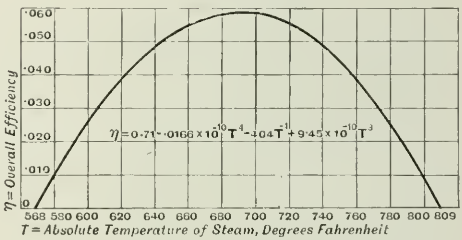


FIG. 6.—CURVE SHOWING THE RELATION OF THE OVERALL EFFICIENCY OF THE 1913 SHUMAN-BOYS SUN-HEAT ABSORBER (WITH NAKED BOILER) COMBINED WITH A CARNOT ENGINE, TO THE ABSOLUTE TEMPERATURE OF THE BOILER STEAM.

spection to be 231° F. as before. (See Fig. 6.) We also see that $\eta_0 = 0$ when T = 568° F. (= T_2, the temperature of the condenser), or when T = 809° F. The latter corresponds with a steam pressure of 131 lb. sq. in. abs., and means that the loss by radiation and conduction from the boilers and by the inefficiency of the mirrors would then be equal to the solar heat received.

Appendix IV. is a bibliography of the subject.

4th October, 1915.

PERCY GRIFFITH, M.INST.C.E., SENIOR VICE-PRESIDENT, IN THE CHAIR.

LAW AND ENGINEERING—SOME POINTS OF CONTACT.

By SYDNEY G. TURNER, A.M.Inst.C.E., Barrister-at-Law.

Introductory.—The close connection which exists between the professions of law and medicine has long received visible recognition in the periodical meetings of the Medico-Legal Society, and the author has for some time past been of opinion that the no less close connection between law and engineering would amply justify the establishment of some similar periodical meeting at which lawyers and engineers could discuss the many subjects which are of mutual interest. A little reflection will serve to show how wide the range of such subjects is—so wide, indeed that it is impossible to deal with them all in the present paper. Writing in 1911, Lord Justice Fletcher Moulton (as he then was) said in the course of his introduction to Mr. L. W. J. Costello's volume on "The Law relating to Engineering:"* "The profession of an Engineer involves much more than mere engineering knowledge or even executive skill. In a large proportion of the matters in which he is consulted he has the responsibility of giving advice, and that advice often relates to acts in which the rights of third parties are directly or indirectly involved. This consideration alone would make it desirable that he should have a sound knowledge of such branches of the law as bear upon the questions he has to resolve. But his need of clear legal conceptions does not depend on this alone. He has not only to administer, but often to frame, contracts of a character which, beyond doubt, renders them the most complicated of any that have to be interpreted and pronounced upon by our Courts, and their nature is such that he can only pass on the responsibility to professional lawyers to a small extent. The rest deals with matters so technical that it must remain in his hands." The general relation of law to engineering could hardly be stated more clearly; and if it is necessary for the engineer to possess some legal knowledge for the proper exercise of his profession, it is no less necessary—as may be seen from the result of a thousand cases—for the lawyer who is conducting a technical case to have at least such a bowing acquaintance with engineering as to enable him intelligently to

* Published by the Society of Engineers (Incorporated).

cross-examine the expert witnesses on the other side. In the present paper the purpose of the author is to make as wide a survey as possible of the field of engineering practice, with a view to ascertaining some of the more important points of contact between law and engineering.

Expert evidence.—Before carrying out this plan in detail however, it will be convenient to consider some points of contact that are common to every branch of engineering. And first, as to expert evidence. If the examination and cross-examination of witnesses is an art, so also is the giving of expert evidence in a convincing and unshakeable manner. It is not necessary to repeat here the old story of the classification of liars into three kinds—the superlative class being the expert witnesses—for although it may have some merits as a jest, the idea upon which it is based is entirely false. Suffice it to say that although the art of the expert witness can only be acquired by long experience, there are many questions as to the rules of evidence and the permissible limits of cross-examination that are of common interest to the lawyer and the engineer. As a general rule the mere opinion of an individual is inadmissible as evidence of a material fact. To this rule, however, there has long been an exception in favour of the admissibility of the opinions of skilled witnesses whenever the subject is one upon which competency to form an opinion can only be acquired by a course of special study or experience. Observation shows that the experienced expert in giving his evidence in chief, speaks with authority and conviction, but is careful to avoid the appearance of mere advocacy. Before going into the box he endeavours to appreciate the case of the other side and to anticipate and consider possible lines of cross-examination, remembering that if he has expressed a different opinion at other times, this may be put to him, and if denied, be independently proved; and that he must be prepared to face a searching inquiry into the grounds or reasoning on which his opinion is based.

Engineer as Arbitrator.—The field of arbitration is another ground upon which the lawyer and engineer frequently meet. Either may be called upon to act as arbitrator, so that both must have a thorough knowledge of the powers and duties appertaining to the office. The position of the engineer as arbitrator is often one of peculiar delicacy and difficulty.

If, however, the contract so provides, as a general rule both employer and contractor must submit to his jurisdiction, for such a clause undoubtedly constitutes a "submission" within the meaning of the Arbitration Act, 1889, the first section of which provides that a submission, unless a contrary intention is expressed therein, shall be irrevocable, except by leave of the court or a judge, and shall have the same effect in all respects

as if it had been made an order of court. The independence of an engineer acting in a judicial capacity as arbitrator in a dispute between a contractor and his own employer is obviously open to question, Nevertheless, the appointment being the result of free contract between the parties, it is not open to the contractor to object to his acting merely upon the ground that he is open to suspicion of bias. On the other hand, of course, the arbitrator is bound to act with judicial impartiality and fairness. In the words of Lord Justice Bowen in *Jackson* v. *Barry Railway Company*, 1893, 1 *Ch*. 238 in appointing the engineer as arbitrator the parties "rely on his professional honour, his practice, and his intelligence; and the contractor certainly has a right to demand that, whatever views the engineer may have formed, he will be ready to listen to argument, and at the last moment to determine as fairly as he can, after all has been said and heard." In certain cases, however, the Courts have held that the contractor is entitled to be relieved from the arbitration clause. For example, if the engineer himself is a necessary witness at the inquiry, or if the question in dispute involves a consideration of the engineer's own conduct, it is manifestly unfair that he should act as arbitrator.

Contracts.—It will be remembered that in the words of Lord Justice Fletcher Moulton, already quoted, he emphasized that the engineer has not only to administer, but often to frame, contracts of a character which, beyond doubt, renders them the most complicated of any that have to be interpreted and pronounced upon by the Courts, and their nature is such that he can only pass on the responsibility to professional lawyers to a small extent. It is not intended here to consider any of the matters which were so admirably dealt with in the lectures delivered by Mr. Costello in 1910-11. What he then said was quite sufficient to show that in the field of contract there is great community of interest between the lawyer and the engineer. In view of the fact, however, that so much engineering work to-day is carried out by municipal and other corporations, it may not be amiss to recall that such bodies occupy a special position. For example, as a general rule a corporation, whether municipal or otherwise, can only contract under seal. To this general rule there are three exceptions, viz.: (*a*) acts very frequently recurring; (*b*) acts too insignificant to be worth the trouble of affixing the Common seal (*Church* v. *Imperial Gas Light Company*, 1838, 6 *A. and E.*, 846; *Mayor of Ludlow* v. *Charlton*, 1840, 6 *M. and W.*, 815): (*c*) where the purposes for which a corporation is created render it necessary that work should be done or goods supplied to carry those purposes into effect, and orders are given by the corporation in relation to those purposes, if the work done or goods supplied are accepted

by the corporation, and the whole consideration for payment is executed (*Lawford* v. *The Billericay Rural District Council*, 1903, 1 *K.B.*, 772). In dealing with local authorities, it must be remembered that although a *Rural* District Council is in exactly the same position as a non-municipal corporation in regard to contracting under seal. the law as regards *Urban* authorities is considerably modified by the provisions of section 174 of the Public Health Act, 1875. Sub-section (1) is of such importance as to merit some consideration. It provides that every contract made by an urban authority, whereof the value or amount exceeds fifty pounds shall be in writing, and sealed with the common seal of such authority. The leading case on this sub-section is *Young* v. *Mayor, etc., of Leamington*, 1883, 8 *A.C.*, 517, which was decided by the House of Lords. In that case the defendant council entered into a contract under seal with one Powis, for supplying their district with water. Powis failed to complete his contract and it was put an end to. The council therefore by resolution authorised their engineer and surveyor to enter into a contract for completing the works. For this purpose the engineer and surveyor, as agent for the council, entered into a contract with the plaintiff which was not under seal. The plaintiff fully completed the works, which the council took possession of and accepted, and of which they continued to enjoy the benefit. It was held that the provisions of section 174 (1) of the Act of 1875 are obligatory and not merely directory, and that as the contract was not under seal the plaintiff was not entitled to recover. This case followed the earlier case of *Hunt* v. *Wimbledon Local Board*, 1878, 4 *C.P.D.* 48, in which a similar decision had been arrived at by the Court of Appeal, where plans had been prepared by the plaintiff, an architect, for new offices for the defendants, It would appear, however, that a subsequent ratification under seal of a contract which was not under seal is sufficient to comply with the requirements of the sub-section (*Brooks, Jenkins and Co.* v. *Torquay Corporation*, 1902, 1 *K.B.*, 601). It has been held that contracts for a less amount than fifty pounds need not be under seal nor in writing (*Hunt* v. *Wimbledon Local Board, supra*). Nor does the sub-section apply to a contract the value or amount of which in fact exceeds fifty pounds if the parties at the time of entering into it did not contemplate that it should exceed that sum (*Eaton* v. *Basker, etc.*, 1881, 7 *Q.B.D.*, 529).

Certificates.—Before passing to a brief consideration of the points where law touches the practice of each of the principal branches of engineering, one other general matter must be mentioned, namely, the responsibility of the engineer in the giving of certificates. In ascertaining the amount due to a contractor, the engineer is acting in a quasi-judicial capacity,

and in the absence of fraud an action will not lie against him for negligence in the performance of this duty. It has been held, however, that the ordinary clause providing for the giving of certificates during the progress of the work is not a submission to arbitration, nor is the certificate itself an award. Contracts are frequently drawn so as to make the giving of a certificate by the engineer a condition precedent to payment. In such cases the amount of the value of the work, although it becomes due on completion, cannot be recovered until a certificate has been given. The question of the finality of a certificate when the contract contains an arbitration clause was discussed in *Robins* v. *Goddard*, 1905, 1 *K.B.*, 294. In that case the contract provided for payment of the contractor under certificates issued by the architect, but it was further declared that " No certificate shall be considered conclusive evidence as to the sufficiency of any work or materials to which it relates, nor shall it relieve the contractor from his liability to make good all defects as provided by this contract." It was further provided that in case any dispute or difference should arise (with certain specified exceptions) it should be referred to arbitration, and the arbitrator should have power to open up, review, and revise (*inter alia*) any certificate. In an action by the contractor against the building owner to recover sums due on certificates issued by the architect, the defendant set up by way of defence and counterclaim that the work done and materials supplied were defective and unsuitable, and not in accordance with the terms of the contract. It was held by the Court of Appeal that the defendant was entitled to set up this defence and counterclaim on the ground that the arbitration clause destroyed the finality of the certificates.

Municipal Engineering.—Perhaps there is no branch of engineering practice which is so closely bound up with the law as that of municipal engineering. The municipal engineer is charged with the administration of a large number of complex Acts of Parliament and he must be possessed of a sound knowledge of the general principles of the law and practice of local government. On this matter the author can speak from his own experience, and this must be his excuse for dealing with this branch of engineering first and at some length.

Sewerage and Drainage.—Consider, in the first place the work of the municipal engineer in connection with the sewerage and drainage of his district. The preliminary question of what is the meaning of the terms " sewer " and " drain," (which it is not proposed to discuss at length in this paper) has demanded the attention of the House of Lords—and many have thought that even they have not solved the puzzle—yet, municipal engineers are frequently called upon to decide specific cases in

the ordinary course of their daily work. The case considered by the House of Lords, to which reference has just been made, was *Wood Green Urban District Council* v. *Joseph*, 1908, *A.C.*, 419. In that case a pipe running across the back gardens of several houses took the drainage of those houses into a public sewer. The houses drained into that pipe in pairs, each pair draining into it by a system of pipes shaped like a Y. Three of these pairs belonged to one owner, and the others to different owners. The stems of the Y's receiving the drainage of two houses, belonging to one owner, were admitted to be sewers. The question was as to whether the pipe running across the back gardens was a "single private drain." Two points arose for discussion: first, as to whether the houses were "*connected* with a public sewer" by the pipe in question, as required by section 19 of the Public Health Acts Amendment Act, 1891, inasmuch as their drainage passed through an admitted public sewer (the stem of the Y) before entering the pipe in question; and second, as to whether the pipe in question was a "single private drain." On the first point, a majority of the House were of opinion that the intervention of an admitted sewer between the alleged single private drain and the houses served by it does not prevent those houses from being "connected with a public sewer" by such drain within the meaning of section 19. In other words, there can be a "single private drain" between two public sewers. With regard to the second point, the judgment of the House is very difficult to understand, and is based on considerations which have not been dealt with in any of the earlier cases. The pipe in question was held to be a "sewer" and not a "single private drain," on the ground that section 19 applies only to conduits which (in the words of Lord Atkinson) "sections 23 and 25 (of the Act of 1875) required the owners to provide or see were provided." Now section 23 empowers a local authority to require the owner or occupier of a house which is not sufficiently or effectually drained to make a covered drain emptying into a sewer, or, if there is not a sewer within 100 feet, into a cesspool; and section 25 requires a similar drain to be provided in the case of newly built houses, or houses which are rebuilt. It would therefore appear to follow, as a necessary result of this decision, that the local authority must show that a pipe was a conduit which sections 23 and 25 of the Act of 1875 required the owners to provide or see was provided, in order to establish that it is a "single private drain," even if it takes the drainage of houses belonging to different owners.

With regard to the power to carry a sewer into, through or under any lands whatsoever within the district of a local authority, conferred by section 16 of the Public Health Act, 1875, it should be noticed that this can only be done "if, on the report

of the surveyor, it appears necessary." These words received careful consideration in the case of *Lewis* v. *Weston-super-Mare Local Board*, 1888, 40 *Ch.D.*, 55. It was there held that "the surveyor" referred to in section 16 means a person duly appointed to be surveyor to the authority under section 189 of the Act; and further, that the word "necessary" must be construed as meaning "necessary for the efficient discharge of the duty imposed by section 15 in the way most for the benefit of the public." Also, the person to determine the necessity is the surveyor; and if he exercises his judgment and comes to a conclusion in good faith, the Court will not interfere, even although other courses are shown to be practicable by which the entry on private lands may be avoided. The section further requires that reasonable notice in writing shall be given to the owner or occupier, before proceeding to carry a sewer into, through or under private land. Where a sewer is laid, pursuant to the powers given by this section, compensation in respect of the damage caused must be paid by the local authority under section 308 of the Act. A local authority are not empowered by the section to execute works which will be a nuisance, and will be restrained by injunction from doing so (*Lamacraft* v. *St. Thomas Rural Sanitary Authority*, 1880, 42 *L.T.*. 365).

Highways.—Another branch of municipal engineering work where the domains of the engineer and lawyer overlap is that relating to highways; and here it may be noted that the changing traffic conditions of recent years have not only produced many engineering problems but have also resulted in the raising of a number of novel legal points. Before mentioning some of the actual cases that have arisen, however, it may not be amiss to say a few words as to the general law relating to the liability to repair highways. It does not follow that, because a road is dedicated to the public and becomes a highway, the highway authority are liable for its repair and maintenance. Prior to the passing of the Highway Act, 1835, no distinct act of adoption was necessary in order to make a parish liable to repair a public road; if the road was public, the parish was at common law *prima facie* bound to repair it (*R.* v. *Inhabitants of Leake*, 1833, 5 *B. and Ad.*, 469). Since 1835, however, some formal act of adoption has been required before a highway authority becomes liable for the repair of a new highway. This formal adoption may now take place in either of three ways—viz.: (*a*) the formalities prescribed by section 23 of the Highway Act, 1835, may be observed; (*b*) a highway may be adopted by notice declaring it to be a highway repairable by the inhabitants at large, under section 152 of the Public Health Act, 1875, or section 41 of the Public Health Acts Amendment Act, 1890 (in districts in which that section is in force); (*c*) a highway may be adopted by notice

under section 19 of the Private Street Works Act, 1892, in districts in which that Act is in force. In the case of a highway dedicated since 1835 there is no liability on the part of the highway authority to repair unless one of these three courses of procedure has been followed (*Eyre* v. *New Forest Highway Board*, 1892, 56 *J.P.*, 517).

Some cases may now be mentioned dealing with the liability of a local authority for damage caused by the manner of repair—*e.g.*: by the use of tar—which are of peculiar interest at the present time. The leading case is *West* v. *The Bristol Tramways Company*, 1908, 2 *K.B.*, 14, where the plaintiff, a market gardener, successfully claimed damages for injury to plants and flowers caused by the fumes emanating from creosoted wood paving. The case was decided on the ground that the defendants had no statutory authority to use creosoted wood, but that their only statutory obligation was to pave, and a material which would not have caused damage might have been used. In these circumstances, having elected to use creosoted wood, they did so at their peril, and consequently were held liable for the damage caused. The principle of this case has since been applied in a case against the Kent County Council (decided in the County Court), where a cow was killed through drinking water which had been polluted by tar washed from road surfaces. In this case, as in the Bristol case, it was held that the treatment of the road with tar was not the only method available and was not therefore absolutely necessary. Before leaving this part of the subject, two other cases are worthy of attention, The first of these was tried in the Swansea County Court and damages were recovered against the Glamorganshire County Council, who had omitted to warn the public of extensive tar-spreading operations which were in progress. In the other case, which arose in Ireland, a cyclist recovered damages against an urban district council for injuries received owing to the slipperiness of a highway which had not been sanded after tarring. In this case, however, the jury found negligence against the Council.

Private Street Improvement Works.—Another branch of municipal engineering practice which is full of pitfalls for the unwary is that concerned with the execution of works of private street improvement. The comparative advantages of working under section 150 of the Public Health Act, 1875, and the alternative code provided by the Private Street Works Act, 1892, in itself provides plenty of scope for discussion. But in selecting a topic for discussion in the limited space now at the author's disposal, none appears to be more fruitful than the preparation of the apportionment. The question sometimes arises as to whether, in case of error in or invalidity of an ap-

portionment, the surveyor has jurisdiction to make a second apportionment The general rule to be evolved from the cases is that when the first apportionment is for any reason a nullity—as for example in *Elsdon* v. *Hampstead Borough Council*, 1905, 2 *Ch.*, 633, where an owner was erroneously omitted—the surveyor is not *functus officio*, and a second apportionment can be made. Under section 150 of the Public Health Act, 1875, if there is any dispute as to the proportion of expenses to be borne in respect of any premises, the matter is to be determined by arbitration. The apportionment, however, is binding and conclusive on an owner, unless within three months from the service of the notice on him by the local authority or their surveyor of the amount settled by the surveyor to be due from such owner, he shall, by written notice, dispute the same (section 257 of the Act of 1875). The jurisdiction of the arbitrator is confined to the ascertainment of the proportion of expenses to be paid by a defaulting owner. He cannot inquire into the necessity for the works or the reasonableness of the expenses (*Bayley* v. *Wilkinson*, 1864, 33 *L.J.M.C.*, 161).

Gas Engineering.—Turning now from municipal engineering to other branches of engineering practice, it will be seen that the lawyer and the engineer have still much in common. For example, parliamentary authority for the supply of gas must be obtained either by special Act or by a provisional order, which is afterwards confirmed by a public Act. Whichever course may be adopted, and whether the supply is to be by a company or by a local authority, the engineer must be familiar with the procedure and practice of the Committee room. "Parliamentary authority having been obtained" (the author is now quoting from the Introduction to Michael and Will's well-known work on The Law Relating to Gas and Water) "certain consequences follow; the company obtain power to construct their works, and if need be to take land compulsorily; they have certain limits assigned to them; they obtain power to break up the public streets for laying and repairing mains and pipes. They obtain power to charge a maximum or standard price, and are given summary remedies for recovering that price by cutting off the supply, by warrant of distress, as well as by action in any court of competent jurisdiction. On the other hand, the company come under many obligations and restrictions; they are restricted to definite lands for the manufacture and storage of gas; they may be compelled by consumers to afford them a supply of gas; and such gas must be of the prescribed illuminating power, pressure, and purity." Here is a wide field for discussion, and a glance at the field of water engineering shows that there an even greater community of interest exists between law and engineering practice.

Water Engineering.—Take for example the difficult questions that arise in connection with subterranean water. The leading case on this subject is *Chasemore* v. *Richards*, 1859, 7 *H.L.C.*, 349, in which the appellant, a millowner upon the river Wandle, had for upwards of sixty years enjoyed the use of the water in the river for the purpose of working his mill. The river was, and always had been, fed and supplied above the mill of the appellant by (among other sources of supply) the rainfall upon a district of many thousand acres in extent, which, either by streams or by percolating through the strata, found its way into the river. The local Board of Health for the town of Croydon dug a well upon their own ground, within the above district, and by constantly pumping, abstracted large quantities of water, which would otherwise have found its way underground to, and have been applicable and serviceable to, the mill of the appellant. The natural effect of such constant pumping would be the sensible diminution of the water supply of springs and streams in the vicinity. The question was whether the appellant could maintain an action for the interception of the underground water ; and it was held that such an action was not maintainable. It must be remembered however, that such water as an owner does in fact receive through underground undefined channels, he is entitled to receive in its natural state of purity ; so that it has been held that the owner of a well is entitled to an injunction to restrain its pollution by his neighbour's cesspool (*Womersley* v. *Church*, 17 *L.T.N.S.*, 190).

Electrical Engineering.—The necessary limits upon the length of a paper of this character render it impossible to do more than indicate some of the more important topics, each of which might form the basis of future discussion. Similar examples may be found in connection with Electrical Engineering. Thus, in connection with electric lighting undertakings—as in the case of gas and waterworks—questions of procedure and also points relating to the breaking up of streets arise ; while in connection with tramways and light railways further questions at once suggest themselves. As an illustration the recent case of *The Charing Cross, West End and City Electricity Supply Company* v. *The London Hydraulic Power Company*, 1913, 3 *K.B.* 442, may be referred to. This was an action brought by the plaintiffs to recover damages for injury to their cables in four different streets caused in each case by the bursting of the defendants' mains. The bursting of the mains was not due to any negligence on the part of the defendants, and the question for decision was whether they were under any liability as for nuisance. Two of the mains were laid under a private Act which was silent as to liability for nuisance, but the other two had been laid under a later Act which contained a clause to the

effect that nothing in the Act should exempt the Company from liability for nuisance. The later Act further provided that the two Acts should be " read and construed together as one Act." It was held that the defendants were liable as for nuisance in the case of the two mains laid under the later Act ; and further that the effect of the two Acts being read together was to take away any privilege of the defendants under the earlier Act, and that consequently they were also liable as for nuisance in the case of the two mains laid under that Act.

Conclusion.—Although it is feared that this paper is open to the criticism that it is of so discursive a nature as to be of little practical value, the author ventures to hope that at least he has succeeded in the endeavour to indicate the number and variety of the subjects in regard to which the lawyer and the engineer may meet on common ground ; and further that in the course of the discussion opinions may be offered as to the desirability or otherwise of establishing some periodical meeting, open to the members of both professions, at which such subjects could be discussed.

Discussion.

The **Chairman** proposed a vote of thanks to Mr. Sidney Turner for his paper. With regard to the suggestion at the end of the paper that it might be desirable to establish periodical meetings at which lawyers and engineers could meet for the discussion of subjects in which both were interested, that point had been considered by the Council, and it had been agreed that, as soon as an opportunity arose for arranging such meetings, the Council would avail themselves of it. The members of the Council were agreed as to the utility of the suggestion which had been made by the author. The paper dealt with subjects in which the two professions were constantly brought in contact, and he felt sure that the vote of thanks to the author for his paper would be heartily supported.

The vote of thanks was carried unanimously.

Prof. Radcliffe, Head of the Department of Municipal and Sanitary Engineering, Municipal School of Technology, Manchester, wrote :—

" There can be no doubt regarding the usefulness of a paper of this kind, especially when the author is possessed of knowledge which will enable him to deal with the two principal sides of the subjects. Law and Engineering are very closely associated, but they are both highly complex and distinct branches of professional work. Each branch is, in ordinary practice, divided into many sections. There are very few men capable of thoroughly

mastering more than one section. For that reason alone the question may be asked, "Is it desirable that engineers should be encouraged to express opinions on legal matters, or that lawyers should be asked to consider engineering problems?"

Many questions relating to legal matters arise in engineering practice that can be answered only by trained and experienced lawyers, who not only know the Acts of Parliament, but are also aware of the decisions which have a bearing upon the matter under consideration. The engineer can merely give his personal opinion on legal points that arise, but the lawyer has statutory obligations to satisfy, and may be held liable for the consequences of ignorance on his part.

The engineer generally would strongly resent any expression of opinion by the lawyer on engineering matters, though it would often be of considerable help if the lawyer possessed some knowledge of engineering principles. It is desirable that both classes of professional men should, so far as possible confine their opinions to the work for which they have been specially prepared by study and experience.

On the other hand, it is the duty of every man, including the engineer, to make himself familiar with the Acts of Parliament and other obligations with which he has to deal. As an example, an engineer should clearly understand the general principles of the Acts of Parliament which authorise the raising of capital to be employed in the work upon which he may be engaged, such as the Acts relating to limited liability companies or the general or private Acts of a statutory company, and also with the conditions imposed by the Acts. In the case of those responsible for the management of workmen, it is necessary to understand the conditions imposed by the Factory and Workshops Act, the Employers' Liability Act, the Workmen's Compensation Acts, and the Acts relating to Trades Unions.

No engineer will be able to make substantial headway without some knowledge of the general principles of the law, and precedents relating to contracts for engineering, building, shipbuilding and other works of construction in the light of recent cases.

The Municipal Engineer is possibly the best example of engineers who are directly in touch with legal matters. He has frequently to act as arbitrator, valuer, expert witness, and engineering adviser in Parliamentary and other legal matters associated with Public Health and Local Government. There is no branch of the engineering profession which has to contend with so many Acts of Parliament and Orders of different kinds as the Municipal Engineer, and it would be a great help to him if the Society could see its way to support officially the movement which has been organised by other Institutes interested perhaps to a greater extent, for the consolidation of Acts relating to public

health and other local affairs. Careful observation has shown, even in this example of very close relationship between Law and Engineering, that municipal engineers of the greatest experience carefully avoid giving opinions on legal matters, and await the decision of the Town Clerk, who is really the person responsible to the authorities. The engineer confines his attention to general principles, which appears to be the wisest course."

Dr. William Garnett, on being asked to open the discussion, said that he felt that a man in any one profession had an enormous advantage if he had a working acquaintance with some other profession, and that was particularly so in the case of the lawyer. There were well known cases in which barristers had made a great name because they had been chemists or engineers as well as lawyers, or had had an intimate acquaintance with some profession other than their own, especially engineering. The author of the paper had given the meeting many examples of the necessity of an engineer having something more than a bowing acquaintance with law, and especially of those branches of law with which his duties were concerned.

He thoroughly sympathized with the author in the difficulty which he had described with regard to sewers and drains. If he rightly remembered the Public Health Act, the definition of a sewer as distinguished from a drain (passing through private land) was inverted in London as compared with the provinces. The case mentioned in the paper was a provincial case. It was many years now since he had looked up that subject. Only recently he had been interested in a contract in which it was a question whether points which arose should be settled by an engineer or by a lawyer. He was quite certain that, if the matter were referred to a lawyer, that lawyer ought to be a man who had a special knowledge of engineering, so that he would be able to estimate the true value of the particulars as set forth in the clauses of the contract.

Mr. J. W. Gordon, K.C., said that he had been particularly interested in the suggestion that facilities should be arranged for the meeting together of lawyers and engineers for the discussion of matters of common interest. He could not speak from the engineer's point of view, but he should think that from the lawyer's point of view such meetings would be a very great advantage. He certainly should be very glad indeed to have the opportunity of comparing notes with engineers in, so to speak, their own surroundings.

The difficulty which Mr. Turner had felt in dealing with the subject, arose from the fact that it ramified so much, and that, he took it, would be true whatever class of industry or professional

interests was considered. The fact was that law necessarily extended over the whole range of our activities, and the consequence was that nobody could afford to be completely ignorant of law. He dared say that it was to a very large extent forgotten to-day that Blackstone's Commentary was originally written, not with the idea of its being a book for law students in any special sense, but with the idea that a general knowledge of the principles of law was essential to a liberal education. That was a very obvious proposition, and he ventured to think that it was a matter for regret that it had so much passed out of sight. The study of law had come to be looked upon as the exclusive province or the exclusive duty of a profession dedicated to advocacy or in other respects to the service of the law; but the older and wider view was, he thought, the sounder. It had been abundantly demonstrated that evening that, so far as the relation between engineers and their work was concerned, it was absolutely impossible for them to be efficient without a very extensive knowledge of, at least, the principles of law. He did not speak of the knowledge which they necessarily gained in practice of formulas and that kind of thing, which one hunted up from textbooks. There was generally a good deal of lore but very little law about them. He would like to draw attention to the importance of a general knowledge of the principles of law and the way in which those principles were applied on a large scale to the solution of the problems which engineering, amongst other professions, presented.

He was concerned many years ago with a commission that was appointed by the Government of Trinidad in connection with the affairs of a Pitch Lake Company. Trinidad pitch enjoyed a very great reputation, and that was largely through the work of a company which held the concession of the Pitch Lake. Great difficulties arose from the fact that there were other deposits of pitch which were of inferior quality, but were sold for what, in fact, they were—pitch from Trinidad, and so deteriorated the reputation of the company's pitch. The company was interested in by far the largest output of the material, and was, of course, anxious to get rid of the damaging competition of the inferior article. The inferior pitch deposits were inspissated asphalt which lay upon a particular part of the land between the Pitch Lake itself and the sea. They were, in fact, asphalt which had overflowed the rim of the lake many years previously, flowed down a gorge into the sea, and rested there, and, in their travels, had been contaminated with sand, and, in the course of time, hardened by the sun. The deposits were quite extensive, although very small in comparison with the deposit in the lake. They were owned by a few small owners who sold the material. The company took a rather high-handed course. They invented

the notion that pitch lying over land was land, and was liable to give lateral support to the adjacent surface. The doctrine was, of course, wholly inapplicable to a deposit such as pitch. What happened was that when one began to excavate pitch from a certain spot, the excavation lowered the level, and drew upon the whole deposit of pitch at a higher level than its own, or a level higher than that to which the excavation was carried. By getting hold of even a small area of pitch land in the deposit a digger could draw indefinite quantities of pitch. The company took advantage of that fact, and provided itself with plots of pitch-yielding land all over the area. Having entrenched themselves in that position, they applied for injunctions on the ground that they were entitled to lateral support to prevent neighbouring owners of pitch from drawing pitch at all. The case was very much discussed at the time, and it came before the Privy Council, and that body held that the owner was entitled to lateral support. and that an injunction to restrain the pitch owner from abstracting his own pitch from a neighbouring plot should therefore go. That was a very unsatisfactory decision of the question, and it gave rise to an *impasse* which had to be cleared up by legislation. The whole difficulty arose because the question had not been adequately considered by a lawyer and an engineer in consultation. The remedy was found in appointing a commission, which consisted of an engineer and a lawyer, and they were able to devise legislation which, he believed, had worked to everybody's satisfaction. The real difficulty was that, whereas the doctrine of lateral support had been evolved in reference to solid land which could give support to weighty structures, the pitch (upon which it was only possible to erect small cottages or sheds built of poles and laths and things of that kind) had applied to it the rules which had been worked out for the case of solid ground. From the engineer's point of view, the difference between those two things sprang to the eyes, but the engineers who had to consider the question in Trinidad were not sufficiently familiar with the doctrine of lateral support to appreciate where it failed to meet the circumstances of the case ; and, on the other hand, the lawyers who had to consider it were not sufficiently acquainted with the physical law which was the basis of the doctrine of lateral support, and they applied the doctrine in an indiscriminate way to a subject-matter to which it had no proper application.

That case, he thought, indicated in a very striking way the manner in which the lawyer and the engineer should collaborate. He thought that they could generalise from such a case. He doubted very much whether a mere reference to Acts of Parliament, schedules, and contracts at all exhausted the subject. It seemed to him that, for the due understanding of any question

of law, it was necessary to be able not only to formulate rules, state precedents, and quote authorities, but to appreciate what it was in the nature of the relations which made a particular system of rules or formulæ applicable to a particular case. They needed to be able to understand the physical or social situation which gave rise to the necessity of applying the rules which had been elaborated as the result of experience. He thought that the relationship between the engineer and the lawyer would be most fruitful when it led to the contemplation by the engineer of law in its broader and more liberal aspects, and the contemplation by the lawyer of the large phenomena of nature which gave rise to the question which had to be solved.

Mr. Harry Geen said that they had listened to a very interesting paper as to matters and contracts in which the combination of lawyer and engineer was very desirable in many cases, but he thought that they must discriminate between town authorities and country authorities. In a large town where there was a legal staff which took charge of such matters, they did not care to be interfered with by an engineer. He was an engineer before he went to the Bar, and he could say that with those who had country experience in engineering the contrary was quite the usual thing. Where, for instance, in a rural district the clerk to the district council had to draw up a contract for sewerage or waterworks, he would often attempt to shift the responsibility for the terms of the contract upon the engineer. Therefore it was very desirable to get hold of the principles which were applicable to such cases.

He was afraid that he must differ from the last speaker, because he thought that principles of law in general were not sufficient alone and that they must get down to details or there would be very great trouble indeed. The engineering profession had not the fatal facility that an architect had who could go to his institution, and, for a shilling, buy a form of contract which was supposed to apply to every conceivable condition under the sun. A few months ago he was very profitably engaged in that room for six days in unravelling the intricacies of such a contract as applied to a particular set of circumstances. He rather thought that the legal profession would be very glad if the engineering profession would try to adopt a form of contract which could be easily obtained.

With regard to arbitration, recent cases had created such a state of things that hardly an arbitrator knew what his position really was, especially if he was an engineer connected with the works in question. The position which was taken up by the quasi-arbitrator, as he was called, seemed to be very unfair. The quasi-arbitrator was the engineer who settled the accounts of a

contract without any reference at all to the contractor. That was a position which contractors ought to rebel against. He had a case before him only a week or two ago in which a contractor had done work amounting to some hundreds of pounds, but he was allowed by the architect the sum of only £18, no explanation being given. According to the contract, the architect was to act as an arbitrator, and, as he understood it, if he could act as a *quasi*-arbitrator he need not take any notice of the contractor's contentions, but could make up his figures somewhat in the nature of a valuation. His certificate being final, the contractor had to take it or leave it. The arbitrator should be a real arbitrator. If he was a mere valuer, let him be called a valuer.

There was a matter referred to in the paper in which it was very important indeed that the engineer and surveyor should know something of law, and that was the question of private street improvement works. Those who had had any experience in drawing up plans and apportionments for private street works knew that they had to be very careful indeed to follow exactly the Act of Parliament, whether they were working under the 1875 Act or the later Act. After they had done their work it was adjudicated upon, in the country, by a bench of magistrates. That might be all very well in towns where there were stipendiary magistrates who had had large experience of such matters; but he had a case of private street works some years ago in which the adjudicating authorities were all country squires brought from rural retreats miles away, who hardly felt the necessity for a pavement, and who certainly had had no experience in the matters they had to consider. They altered the work here and there until, when they had done, he did not know what they really required. That was one of the difficulties which surveyors had. Even when they had a knowledge of the Act of Parliament under which they had to work, they might be overruled by an inexperienced authority, and that would make their work much more difficult than it ought to be.

Perhaps Mr. Turner would explain what he meant by saying that the appointment of an arbitrator was not open to objection on the ground of suspicion of bias. He thought that there was a case not long ago where suspicion of bias was enough to bar the arbitration clause. He quite agreed with the next paragraph, which said that where an architect or contractor was to be a witness on an enquiry he should be barred from acting as arbitrator.

Mr. Turner: My phrase is not a very happy one. If you add, after the words "suspicion of bias," "merely because he is the architect," I think that that will make it clear. That is what I meant.

Mr. Geen : With regard to the sealing of contracts for services, he did not know whether it was made quite clear that an engagement by an authority for the provision of plans and so on ought to be under seal. The Institution of Civil Engineers, of which he was an Associate Member with Mr. Turner, some little time ago thought it necessary to send out a circular to all its members, calling their attention to the fact that contracts with authorities for the provision of plans, etc., ought to be under seal. He knew a few cases where authorities had been rather chary of sealing such contracts.

With regard to highways, he thought that an addition ought to be made as to the law of their dedication, and that was that there might be an implied dedication by user without interruption from the owner. He thought the instances which the author had given really met most of the circumstances ; but he had a case in Devonshire not very long ago where an unfortunate man had allowed carts to go over a private roadway and had not stopped them, and the judge held that a dedication could be implied from the circumstances.

Mr. Gratian Mould joined in congratulating Mr. Turner on his extremely interesting paper. The paper dealt with the question of expert witnesses, which was always a very vexed one, and it revived the time-honoured jest about them. A variation of the jest was given by a very learned judge, whose brother did a large amount of business as an expert witness. When the judge heard that expert witnesses were divided into three classes he said : " But if you knew my brother there would be a fourth class." Dealing seriously with the matter, it had always struck him (Mr. Mould) that an expert witness was in an extremely difficult position. Suppose the case of valuing a house for compensation. If the expert was acting as sole arbitrator he would put the value of the house at, say, a thousand pounds. If he was called as a witness for the claimant and said that the house was worth a thousand pounds, that sum would be substantially discounted. And, equally, if he was on the other side, and put the value at £1,000, his figure would be substantially increased. The expert ought to be regarded as giving the highest figure to which, in any reasonably conceivable circumstances, his client could be entitled, or, conversely, the lowest figure which, in any reasonably conceivable circumstances, his client ought to pay. Everybody acquainted with such matters would understand the nature of his evidence. It had been seriously urged that the expert witness should be relieved from the oath, because if he gave in evidence exactly that figure which he would award as an arbitrator, his client would not get justice. Experts must magnify on the one hand and diminish on the other.

He did not quite follow Mr. Turner when he said that if the expert had expressed a different opinion at other times and denied it, independent proof could be given. He did not know any means by which that could be done. A witness could not be called to say that an expert had at another time expressed a contrary opinion. A letter which he had written might be put to him, but the cross-examiner would be bound by his answer. It was a matter between the expert witness and his own conscience. Perhaps Mr. Turner had another meaning in his mind than that which occurred to him (Mr. Mould).

He quite agreed that the practice of an engineer acting in a judicial capacity in a dispute between a contractor and his employer was open to question. The same consideration would apply to surveyors and architects. Even given a conscientious man with every desire to do justice between the parties, yet, if a man had been associated with a matter from the onset, he must more or less have formed some opinion previously, and he could not bring such an open mind to the consideration of the matter as he could if he were entirely independent and had no preconceived conviction at all.

With regard to the paragraph in the paper which spoke of engineers being relieved from the arbitration clause, Mr. Geen seemed to think that in many cases the engineer might be a necessary witness. He (Mr. Mould) thought otherwise. The cases in which the Courts had said that the engineer was not a proper person to decide were, he believed, mainly cases where the engineer's own conduct formed the subject of attack or defence. If an essential portion of the case was, for instance, whether or not the engineer had furnished proper plans within the proper time, the engineer was not the right person to decide whether he himself had performed his duty.

With regard to certificates, Mr. Turner said that contracts were frequently drawn so as to make the giving of a certificate by an engineer a condition precedent to payment. That was so, but there were cases in which even, although the contract in terms provided that the certificate should be a condition precedent to payment, yet, if there had been any improper conduct on the part of the employer in connection with the engineer, that difficulty could be got over. He had a case a short time ago where a builder was putting up a mission church, and where the people for whom the church was put up interfered with the architect at every point. He (Mr. Mould) did not allege bribery or anything of that kind, but he proved that the employer had so interfered with the architect that the architect was no longer left in an independent position, and that, although the contract provided in terms that the certificate should be a condition precedent to payment, the

certificate ought to be dispensed with, and the court upheld that contention.

On the question of highways Mr. Turner had drawn attention to the fact that liability might arise from the manner of repair by a local authority, for instance, in the use of tar. The local authority was, probably, liable where it defectively repaired a road; but, in general it was not liable where it did not repair at all. If it did anything in an improper manner it might be liable, but where it "went the whole hog," and did nothing, it was merely a case of non-feasance, and there was no liability. Some years ago a man riding on the top of a tramcar lost an eye through a tree which overhung the public highway, and the jury gave him a thousand pounds. It was decided on legal grounds that, as the authority had done nothing whatever to the tree, and as the tree had merely grown by itself until it overhung, the claimant could recover no damages. Perhaps the local authority ought to have clipped the tree, but they had done nothing, and it was held therefore that they were not liable. That showed the broad distinction in these matters.

With regard to water engineering, it was a curious condition of affairs that if you dug a well deeper than your neighbours, and took away the whole of his water, you had not to pay anything; but if you polluted any part of it you had to pay. It seemed that there was compensation for the lesser but none for the greater injury.

With regard to the study of law by engineers and the study of engineering by lawyers, they all recognised that, as a rule, it was best for each man to stick to his trade; but there were so many points where law and engineering, just in the same way as law and architecture or surveying, came into contact, that every surveyor and engineer must, he thought, of necessity be in part a lawyer with regard to his own particular domain. He did not think that there was any risk attendant on the engineer being, in part, a lawyer, provided that he acquired sufficient knowledge to show him where he was on dangerous ground and where he ought to obtain legal advice. Just in the same way no lawyer who had some engineering knowledge would go outside the evidence of the experts on his side in a case, but his knowledge would enable him to understand the proofs of those experts and to grasp their meaning more intelligently when they instructed him as to cross-examination.

Mr. Valentine Ball said that he had listened with great interest to the paper, and he had been greatly struck with what it said about arbitration. It seemed to him that that was a matter upon which lawyers might usefully impart a certain amount of information to engineers, who were occasionally called upon to

act as arbitrators. The gentle art of arbitration was not quite so easy as it looked. If the lay arbitrator would appreciate that it required some experience to act in the capacity of a judge, lay arbitrations, he thought, might be a little more satisfactory. There were various elementary points which a lay arbitrator was sometimes inclined to overlook. They would find that the man who was most frequently chosen as a lay arbitrator was one who had had a good deal of experience of arbitrations, and who gave both sides a fair hearing. A friend of his had told him that in one case in which he was concerned an engineer had been appointed to settle a dispute with regard to a motor car. He heard counsel for the plaintiff for a very short time, and then he went into the courtyard of the building to examine the car. He came back and proceeded to give his decision without hearing further speeches or witnesses. That was a ludicious performance of the function of an arbitrator. He could not do better than advise any gentleman who was suddenly called upon to act as arbitrator to read Bacon's short essay entitled *On Judicature*. There he would find the whole duty of an arbitrator admirably set forth.

With regard to expert witnesses, sometimes a technical witness made the mistake of being rather too technical and of using words which the tribunal and the advocates did not quite understand. The simpler and shorter he could make his answers the more effective his evidence would be. There was an historic case of a dispute with regard to a piece of machinery. An expert was called who said that it was obvious that the machinery was not working properly because the gudgeon was overheated. The judge said, " I do not believe a word of what this witness is saying. It is obvious that no gudgeon could become overheated. The gudgeon is a cold-blooded animal ! "

On page 4 the author had made this observation :—" It has been held that contracts for a less amount than fifty pounds need not be under seal nor in writing." That might be so as regarded that particular provision of the Public Health Act, but there were certain contracts for a less amount than fifty pounds which must be in writing, having regard to the provisions of the Sale of Goods Act.

Mr. Turner : I was thinking only of the Public Health Act when I wrote those words.

Mr. Edward Willis said that, in his opinion, Mr. Turner had ably selected leading cases to emphasize his suggestion. The subject was so extensive, especially from an engineer's point of view, that it was utterly impossible to deal with it adequately in a short paper, and he could see that there had been some difficulty in selecting such points as would open up and give a lead

for the discussion. He thought that the remarks of Mr. Gordon on the Trinidad pitch lake were very interesting, and brought forward points for consideration which would be undoubtedly useful to engineers in their practice.

The cases which Mr. Turner had given as leading ones were very ably selected to advance his suggestion of a subsidiary society, at whose meetings the opinions of the two professions could be discussed. An engineer did not wish to be a lawyer or to practise as one, but the municipal engineer especially must be acquainted with Public Health and Highway Law, or he would be sure to let his Council get into trouble some day. They probably had, at times, seen how young engineers, anxious to do well, had, through lack of experience in law, and especially Public Health law, gone astray and unwittingly brought their Councils into legal difficulties. He quite agreed that engineers should take at least an elementary course in Law. In the Surveyors' Institution that was a part of the syllabus of their examination.

He considered the author's remarks about the expert witness were very good. His difficulty was to make a judge appreciate the essential facts of certain details, since in many engineering problems, matters of detail were the principal questions before the court, and sometimes the whole case was decided upon small details. He was sure that the legal element in the meeting would appreciate that it was not always an enviable position to be an expert witness.

With regard to the engineer as arbitrator, he really thought that they must look upon members of the engineering profession as a whole as men of absolute integrity. As had been said, engineers make mistakes, and he thought that a profession would not be of so much good to the public if none of its members did so, since some of the finest examples of work had been evolved through earlier mistakes. His experience proved that the engineer, when acting as an arbitrator, gave, on the whole, just awards. He agreed that the difficulty of the quasi-arbitrator was one with which the contractor had still to contend, but the courts had fairly well defined his position. With regard to certificates, he thought that the engineer should be liable for negligence in the issue of certificates. Mr. Turner had said that the engineer was not liable, but he (Mr. Willis) was nearly sure that there was a case in which the engineer, or possibly it was an architect, had been held to be liable for negligence in the supervision of work and in the preparation of certificates, and, in his opinion, engineers should be prepared to stand by their own certificates where they were able to give proper supervision.

With regard to contracts for small amounts being under seal, he thought that Mr. Turner was solely referring to Public Health Law. There were many cases in which goods of amounts ex-

ceeding one hundred pounds had been purchased by him without contract. In one or two cases, however, the Local Government Board Auditor had thought contracts were necessary, and they had therefore been made long after the goods had been supplied and used. In many cases it was impossible to order materials in small lots, and so comply with the Act. The case of *Young* v. *the Mayor of Leamington*, which was heard in the House of Lords, was always cited in connection with the question of contracts under seal. He could not properly distinguish between equity and law, but it seemed to him that this decision was certainly not an equitable one. Probably every lawyer in the room would admit that it was not justice or equity for the contractor never to have been paid. He hoped that the decision would some day be upset, although he was afraid that was impossible, since it was a decision of the House of Lords.

In dealing with highways, Mr. Turner did not mention the question of extraordinary traffic. Perhaps his reason was that it was such a large subject, and might be a very controversial one.

In connection with some thousands of private street works apportionments he, fortunately, had been compelled to deal with only a few difficult cases in his experience, and these, after reference to the court, had been amicably settled by the engineer for the owners conferring with him out of court. The Private Street Works Act had undoubtedly numerous disadvantages, and he did not think they should be minimised, but it had the one very great advantage that, after the provisional apportionment had been approved and the work carried out, no question of specification or construction could be raised.

Mr. H. T. Chapman said that the question of how far engineers should go in their legal knowledge or in the practice of law was a very moot point. They had always been under the impression that "a little knowledge was a dangerous thing." Perhaps some legal gentlemen would be only too pleased if engineers would undertake some of the legal portion of their duties, because this would probably add to the work of lawyers. Although it was most desirable that engineers should have some knowledge of the law affecting their work, he very much doubted whether it would help them in their practical work. Many points cropped up in the work which they had to carry out, and he was afraid that if these were considered from a legal point of view not much would be done. There was, for instance, the Bristol case, which Mr. Turner had mentioned, in regard to creosoted wood paving. There had been millions of square yards of such pavement laid since, but he had not heard of another case on similar grounds.

One gentleman had mentioned the question of non-feasance

and mis-feasance. In much of the work of repair which they carried out they might possibly be held as guilty, legally, of a certain amount of negligence, but they were protected to some extent by the contributory negligence of the users of the highway, though he was afraid that juries did not always give the same weight to the latter as to the acts of local authorities.

Reference had been made by Mr. Turner to the case of a cow which was poisoned by tar, used on a main road, polluting a pond. A post-mortem examination was held on the cow, and it was proved, he thought, that a bucket of tar had been left in the farmyard, and that the cow had helped itself from it, also that the quantity of phenols in the stomach or intestines of the beast was so large that they could only have accumulated from many miles of main road, whereas the surface water from only a short length of main road entered the pond in the farmyard. He had a similar case in East Kent last summer. Some men were tarring a road, and a bucket of tar was left for a few moments by the roadside. Cows were being driven along the road, and one of them, being rather inquisitive and very dry, consumed a lot of tar from the bucket. A claim was made, which the County Council repudiated, and he was glad to say that it did not go any farther.

With regard to certificates on account, it was only fair to assume that the whole of the work for which the engineer gave his certificate was satisfactorily carried out. There were certain classes of engineering work which could not be tested until a definite portion of the work was completed. He was thinking, for the moment, of reinforced concrete structures. If an engineer had to withhold his certificates until the work was completed to such an extent that he was satisfied that it was structurally sound or in entire accordance with the tests specified, the contractor might have to wait a very long time before he got his money. That would mean, in some instances, that the greater portion of the contract must be completed before any payment could be made on account. No doubt the contractor would consider that a very great hardship.

Mr. Percy Griffith said that he was particularly interested in the subject of the paper. Some years ago he published a small book on Waterworks Law, and he had been greatly consoled by the author having been kind enough to say that he had found the book useful. In one of the leading cases quoted in the paper, *Young* v. *the Corporation of Leamington*, the plaintiffs were the firm with whom he served his articles, indeed, the case was settled just about the time that he went to the firm, and the decision seemed to him a very unfair one.

In his practice he had had experience in giving evidence, both in Parliamentary Committee Rooms and in the Law Courts, and

under such circumstances an engineer was brought into contact with many purely legal points of which he had to get a fairly clear idea, even if he had not qualified in law. His attention had been more particularly directed to the general statute law relative to waterworks engineering in connection with the Institution of Water Engineers. That institution was constantly devoting its attention to the broader legal aspects of water engineering and water supply, and he would suggest some points which, he thought were well worthy the consideration of any water engineer.

With regard to the general waterworks law, the most important Act was the Waterworks Clauses Act of 1847. Now, this was a very old Act, and conditions had changed a good deal since it was passed, and although one must admit that the legislation of that period was a marvel of foresight and skill, yet those who were in constant practice in water engineering felt that the general law was ripe for amendment, and, more particularly, for consolidation. He would not attempt to give a list of the general Acts of Parliament which particularly affected water undertakings, for the list was a very long one, and the water engineer would have a tough job if he made himself familiar with them all.

With regard to Private Bill legislation connected with gas supply and water supply, each undertaking became a law unto itself. It incorporated such of the general Acts as it thought fit, and then made its own clauses. These were governed more or less by the Model Bill, which was the most intelligent thing in existence in connection with Acts of Parliament, because it was subject to periodical modification, and was constantly being brought up to date. He had a great admiration for the Model Bill, and for the authorities who revised it periodically. By that Bill the law took into practical consideration the engineering questions which arose from time to time, and special clauses were frequently introduced to meet special cases. He believed that the Model Bill was now nearly as long as the General Act, and it was about time the General Law was consolidated and brought up to date so that the many standard clauses in the Model Bill could be dispensed with by being incorporated in the General Acts.

A question of special interest at the present time in connection with water supply was the definition of "domestic supply." This was frequently the subject of litigation, and lawyers were having a fairly good time over it.

Another interesting point was the question of standardising the general conditions of contracts, which included the debatable subject of the engineer acting as arbitrator. As Secretary to the Institution of Water Engineers, he was constantly collecting legal decisions on waterworks questions and filing them for the use of the members, so that he was compulsorily getting more or

less up to date in that particular matter. He would suggest that engineers should make a point of collecting legal decisions, and particularly of reading the arguments upon which the decisions were based. They would be interested and sometimes amused.

The suggestion made in the discussion that engineers should study a little law, and that lawyers should study a little engineering, seemed quite sound, but it seemed dangerous if carried too far. He certainly did not think that any engineer should attempt so to grapple with legal matters that he could displace the lawyer and advise without consulting one. That would be vanity and folly combined. Similarly, he did not think that lawyers, even eminent barristers with practice at the Parliamentary Bar, who had special experience in questions of an engineering character, should venture to advise clients on such matters. But, on the other hand, there were, as the author had contended, many points at which the two professions came into contact. Engineers were frequently called upon to deal with legal anomalies which had not been revised in accordance with practical experience, and while they were powerless to upset a legal decision they were interested in getting the law revised in order to avoid the anomalies and difficulties resulting from them. This, however, brought the engineer into an awkward position with regard to the legal profession, because by removing the anomalies of the existing law they would reduce the amount of litigation. Thus this question had to be considered with a little common sense and mutual consideration ; but, on the other hand, he quite agreed that collaboration and discussion on points of mutual interest would be of great value to both professions as well as to the community at large.

Mr. H. G. Kershaw said that the importance of the subject which had been brought before the meeting was more or less recognised by all the professions, and, perhaps, the Public Health side of administration had recognised its importance most. In most of the Universities to which a medical school was attached there was a professorship of jurisprudence, and he thought that on the public health service there were more members who were qualified barristers than in any other class or profession of which he was aware. No one could practise successfully in two professions at the same time, but the advantage of dual training was illustrated over and over again. His own Council had been engaged in litigation for five years in regard to a closing order made under the Housing and Town-planning Act. The owner of the house concerned turned out to be one of the most determined and persistent litigants of modern times. He (Mr. Kershaw) had no hesitation in saying that the fact of the Council having been able to keep their end up, throughout the

litigation, on the common law side and the Chancery side and in the House of Lords, was due, to a large extent, to the foresight of their town clerk in instructing a barrister who was also an engineer. It was hardly necessary to say that that barrister was Mr. Turner.

He (Mr. Kershaw) had had considerable experience in the question of the drafting of contracts. He supposed that such drafting had given rise to as many difficulties as the drafting of wills. He would rather have a contract that was drafted by a lawyer who had no technical knowledge than one that was drafted by an engineer who possessed no legal knowledge.

He thought that the principle of the engineer most concerned acting as arbitrator was a bad one, and that the practice was wrong. There was an underlying principle which would impose the obligation on every one who had to decide anything, to decide in accordance with the principles of natural justice, and it was very difficult for an engineer to act fairly and without bias as an arbitrator in a case where he had been the engineer to the work. They might rely on his professional honour and integrity, but they could not get behind human nature.

As to the lay arbitrator he (Mr. Kershaw) thought that he should not be allowed to sit by himself if he had no legal knowledge, but should be compelled to have a lawyer sitting with him to advise him, just as a Justice of the Peace had to be advised by his clerk. He knew of a layman who had a considerable amount of work as an arbitrator and to whom the mention of an Act of Parliament or a code of by-laws was like the waving of a red rag before a bull. It was often impossible for an arbitrator to come to a just decision on a point without taking into consideration the legal side of the question and the obligations which Acts of Parliament and by-laws or regulations imposed. He thought that both lay arbitrators and expert witnesses could be very well dispensed with and replaced by official arbitrators and witnesses or assessors who were properly trained for dealing with the matters which came before them.

Mr. C. T. A. Hanssen said he thought that from a civil engineer's point of view it was important for an engineer to have legal knowledge, but it should be applied in such a way as to keep both parties out of the law courts. He considered it a wonderful thing, and a great credit to the engineering profession that, of the many thousands of contracts that were carried out every year in this country, so few engineering contracts ever reached the law courts. There must be a good deal of "give and take" between engineer and contractor. The high-class civil engineer had no wish to fleece the contractor, or to treat him unjustly and, when the contractor knew that,

there was a great disinclination on his part to go into Court. The great object of the independent engineer should always be to act in such a way that he did not exasperate the contractor into legal action, and he should, on the other hand, persuade his client so to modify his claim that there should be no necessity for it.

Generally speaking he considered it the most unwise thing a man could do to go to law. It was far better to suffer a little loss or wrong than to squander money and time in such a way, and the engineer who had sufficient tact and discretion to keep clear of the law courts would be appreciated by Corporations and by contractors alike, as the cheapest and most efficient man to employ.

REPLY.

Mr. Sydney G. Turner said that the meeting must take it that his appreciation of the vote of than [illegible] portion to the length of his reply, because he would not detain the meeting long at that late hour.

He had entirely failed if he had not made it clear that the paper was written with the sole purpose of ventilating the idea of a common meeting-ground between lawyers and engineers. His selection of topics was purely arbitrary and was merely intended as a series of illustrations of the kinds of subjects which might be chosen for discussion. Perhaps it was inevitable that the discussion should take the form of discussing the illustrations rather than the main proposition; but the fact that so many speakers had found themselves interested in one or other of the matters that he had indicated was, in itself, he thought, some justification for his main suggestion. He did not intend to suggest that the lawyer should try to make himself into an engineer, or that the engineer should try to trespass on the legitimate domain of the lawyer. All that he suggested was that each should fortify the knowledge that he had of his own profession by some knowledge of the other profession. It was not every lawyer who needed to have a knowledge of engineering, and it was not every engineer who needed a knowledge of law. Many legal practitioners never touched technical cases at all, but he thought that there were a sufficient number of men interested in each of the two professions to make the suggestion which he had ventured to throw out worthy of discussion. If the Council of the Society were to consider it worth while to do anything practical to bring the suggestion to maturity, he should be perfectly willing and anxious to afford any support in his power

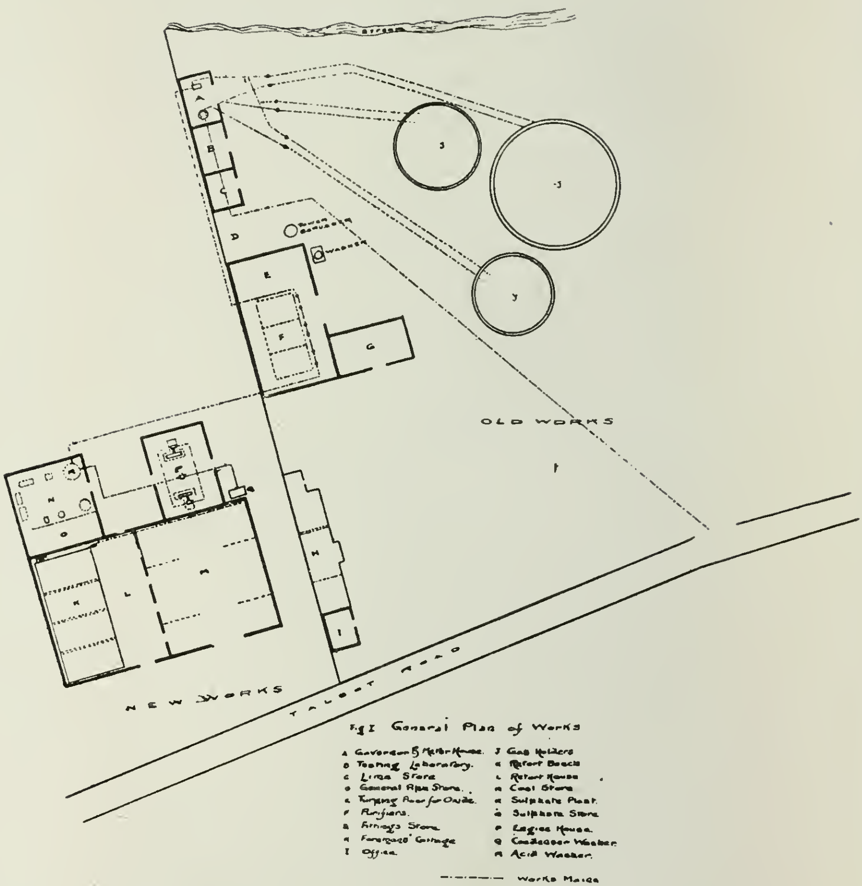


FIG. 1.—PLAN OF HAWKHURST GAS WORKS.

THE RECONSTRUCTION OF A COUNTRY GASWORKS.

By Alec E. Whitcher (Associate Member).

The Hawkhurst (Kent) Gas Company was formed in 1868, with a capital of £2,000, divided into 400 shares of £5 each. At that time the price of gas was 7s. 6d. per 1,000 c. ft. A few items of the cost of the original works, from the meagre information available, are :—

	£	s.	d.
Excavating and building gas holder and tar tanks in puddle	137	0	0
Excavating and masons' work to buildings	547	0	0
Carpenters' and painters' work... ...	146	0	0
Supply and erection of plant, including gas holder, roofs, scrubber, one Yorkshire brick oven to take 5 cwt. of coal, and purifiers, etc.	1,300	0	0
Total	£2,130	0	0

Old Site.—The site of the old works being between two hills, the roadway into the works was very steep, which, coupled with the distance from the railway station, made the cost of coal cartage high, viz., 2s. per ton, and adversely affected the sale of residuals. On the other hand, benefit was derived in the distribution of gas from the natural increase in pressure due to the low position of the works. The additions made before the reconstruction of the carbonizing plant were the erection of two gas holders, one of 28,000 and the other of 8,000 cu. ft. capacity. The original holder, having a capacity of 7,000 cu. ft., was resheeted, making the total storage capacity 43,000 cu. ft. A purifier was added, 7ft. square and 5ft. deep, with the periodical renewal of the carbonizing plant.

In 1913 a secondhand combined gas engine and exhauster was purchased at a cost of £25, and was worked in conjunction with the existing plant, which formerly had no exhauster.

In February, 1913, the directors, finding that the plant had become totally inadequate for dealing with the increasing demand, consulted Mr. Andrew Dougall, M.Inst.C.E. (Engineer and General Manager, Tunbridge Wells Gas Co.), who advised the reconstruction of the works on modern lines. Plans were prepared by the consultant engineer, and the company decided to

adopt a progressive policy, and to appoint an official as engineer, manager and secretary to superintend the erection of the plant.

The new work was begun in March, 1914, and subsequently the author was appointed to the above-mentioned duties, and these notes record some of the none too pleasant experiences when running the obsolete plant during the early winter, in addition to supervising the erection of the new works.

Condition of Old Plant.—The old plant included a brick and slated building which was used as a coal store and retort house. The carbonizing plant had two settings of four retorts and one setting of three retorts on the direct-fired principle, the retorts being of fireclay, oval in shape, 21in. × 15in. by 9ft. long. The vertical washer and tower scrubber, by Messrs. Dempsters, had a capacity of 30,000 cu. ft. per diem. There were three purifiers, water luted, two of them being 6ft. square, and one 7ft. square, all 5ft. deep, and there was a 6in. Parkinson & Cowan governor and station meter. The three gas holders had a total capacity of 43,000 cu. ft. The majority of the works connections were 6in. diameter. A close examination of the old works did not, to say the least of it, fill one with confidence ; the plant had more than fulfilled its duty, and was practically beyond temporary repairs, but had to be kept going at any cost.

Washer and Tower Scrubber.—The washer and scrubber were both absolutely choked up and had been by-passed, and the valves were immovable. After taking off the cleaning plates of each section and applying oil to the valves the scrubber was made workable, and the by-pass was shut, but the washer was in such a condition as to be beyond use.

Station Meter.—The previous non-action of the washer and scrubber resulted in trouble with the station meter, which suddenly ceased to register. It was overhauled by the makers, the drum was taken out and cleaned, and a new solid brass spindle and cog wheels were supplied, but after a month's working the meter again stopped, and after another examination the author came to the conclusion that the meter was practically acting as a washer to the gas. The water taken out of the base of the meter was of a Prussian blue colour, and the ammonia carried forward in the gas corroded the brass cog wheels. The difficulty was overcome by fitting a cast iron cog wheel to guard against a similar occurrence before the new plant came into operation, and this step proved successful.

Purifiers.—The purifiers were in a very bad state, being leaky and patched up with all manner of devices.

Governor.—The governor was out of action, and, there being consequently no control over the pressure, trouble was caused in the district when the holders were changed.

Retort Settings.—After a few weeks' working serious defects

were observed in the arches and combustion chambers of the retorts, which showed signs of falling in.

The Gas Engine and Exhauster badly required overhauling, but it was not possible to do this thoroughly in existing circumstances, and they were kept running with great difficulty.

Experiences in Working.—For a while, during the summer, matters went fairly well, but towards the end of September the stokers (evidently foreseeing trouble in the near future) both left, as also did the previous working manager, who had continued in the company's employ ; and until these vacancies could be filled, the author was obliged to take a little physical exercise at stoking, with the assistance of a boy and a stoker kindly lent by a neighbouring gas engineer.

As soon as labour was again arranged for the heats became very bad on one of the settings, and one side of the furnace caved in, and was patched up with difficulty. The retorts were now proving quite unequal to the increasing demand, and as the new men di l not know the peculiarities of the works, minor troubles were numerous, causing the writer many visits to the works at night time.

The old coal store at this time was being converted for the new purifiers, and as the foundations extended to within a few inches of the working furnaces, a temporary charging platform had to be erected for the stokers to work upon. This, of course, was very inconvenient for the men and difficult for the contractors, but as there was no choice it was all taken in good part. All would have been well, no doubt, had the contractors fulfilled their work in the specified time, *i.e.*, the end of August, 1914, but with the outbreak of war the dislocation of the railway services caused unthought-of delays.

As the retorts should have been renewed at least eighteen months before, their condition can be well imagined, and although every means of assisting the heats was adopted it was of no avail. Stringent measures had therefore to be taken to maintain any supply at all, and in several cases of emergency the writer had fitted on the foul main a $\frac{3}{8}$in. iron cock, which was opened for about an hour after a charge, the exhauster thus drawing in a small percentage of air with the gas. While this was on, the jet photometer had to be closely watched, and it was found that the illuminating power of the gas was not reduced to any considerable extent, the average illuminating power being 15 candles, and by this means the yield per ton of coal was increased from about 10,000 cu. ft. to 11,000 and 11,500 cu. ft, according to the urgency of the demand. The coal used at this time was Holmside, with a small admixture of Cannel. The author found that this method assisted the purifiers, but could be adopted only in cases of emergency, as it would have been risky to have left its management to a stoker.

The difficulties did not end here, for with the darker nights the week-end consumption resulted in two of the gas holders being emptied, the third shewing only a few rivets, and it was subsequently found necessary to circulate a notice to consumers stating that, owing to the delay in completion of the new works, caused by the non-delivery of materials by the railway company, it would be necessary for a short time seriously to curtail the supply of gas for cooking and power between the hours of 6 a.m. and 4 p.m. This relieved matters, and the old works were kept running until the new plant was in working order.

Starting the New Plant.—The new plant, which was wholly new with the exception of the station meter and gas holders, was so arranged that the whole of the 8in. connections were entirely separate from and independent of the old works, and by means of by-passing the old plant supply at the station meter direct into the inlet main to the holders and coupling up the new plant into the station meter, both manufacturing plants were enabled to work into the holder at the same time.

To ascertain whether the air had been expelled from the new plant a blow-off tapping was made on the end of the new main before entering the meter. This consisted of a 1in. main cock, to which was connected, at intervals, a length of pipe reduced to take a flat flame burner, thus showing when all the air had been discharged. The old plant was at the same time supplying rich gas, and as the new portion came fully into action the old was gradually shut down. The change-over took place without any hitch or deterioration in the quality of the gas supplied.

New Site.—The new site having an area of about half an acre, gives plenty of room for future extensions, and was purchased at a cost of £232. It adjoins the old works and is situated on the upper part of a hill 12 feet above the ground-floor of the old buildings. Being level with the roadway and within a few yards of it, the cartage of coals and residuals is much easier. The subsoil is sandy, showing traces of clay and with a lower stratum of sandstone.

Foundations.—The foundations consist of a layer of concrete averaging 2ft. 9in. in thickness and extending beyond the main walls from 6in. to 9in. There are three courses of brick footings of an average thickness of 2ft. 6in.

Retort House.—The new retort house is 43ft. long by 29ft. 6in. wide, and the height to the eaves is 19ft. The walls are built of red bricks, the main walls being 14in. thick, and having piers 2ft. 4in. wide at the angles of the building, with three intermediate piers of the same size. The gable ends are carried 6in. above the slating, and finished with a York stone coping and lead flashing.

The building provides for four settings of six retorts, of which

Fig. 2.—Hawkhurst Gas Works—General View.

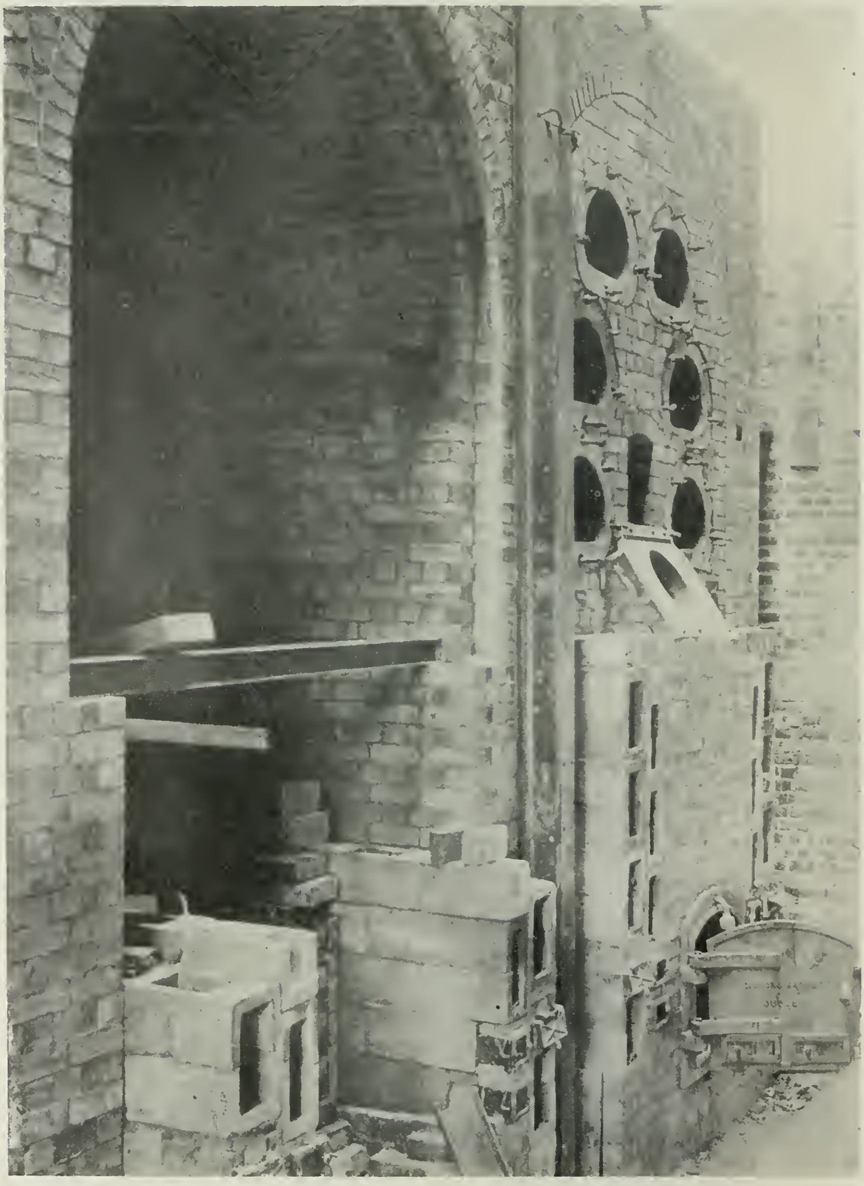


Fig. 3.—Hawkhurst Gas Works—Retort Settings.

three arches, 9ft. span and 7ft. 7in. high, have already been constructed. The depth of the furnace floor below the charging floor is 7ft. Only fire bricks of approved quality have been used, except above the two $4\frac{1}{2}$in. rings which form the arches. The two filled arches are 11ft. $4\frac{1}{2}$in. from front to back, and provision has been made for two more of the same size. There is a brick chimney inside the retort house 3ft. square at the base and resting on a concrete foundation 3ft. 3in. thick. The walls are of red brick 9in. thick, with an inner lining of $4\frac{1}{2}$in. of fire brick, the chimney being 40ft. high and strengthened by $2\frac{1}{2}$in. × $\frac{3}{8}$in. flat iron bars and 3in. × 3in. × $\frac{3}{8}$in. L irons bolted together from each corner.

A ladder is provided for access to the top of the settings. The four front and four back buckstays are 8in. × 5in., carried to the bottom of the bench and fixed in cast-iron shoes, securely bolted into the concrete. The six end buckstays are 10in. × 5in. × 30 lbs., 11ft. 10in. long, secured in a similar manner. The top ends have flat eyes to receive the three $1\frac{3}{4}$in. diameter tie rods. The four cross joists are 6in. × 5in., secured to the buckstays with angle iron brackets. The mouthpieces are all self-sealing. The ascension pipes, bends, arches and dip pipes are all 6in. in diameter.

The hydraulic main consists of mild steel plates $\frac{3}{8}$in. thick at the top, $\frac{1}{4}$in. at the bottom, and $\frac{3}{8}$in. at the end, the top and end angles being $2\frac{1}{2}$in. × $2\frac{1}{2}$in. × $\frac{3}{8}$in. In each section sight glasses and two handholes for cleaning are provided, also a patent plunger for clearing the 3in. tar drain off the valve from the main. The rivets are $\frac{5}{8}$in. at $2\frac{1}{4}$in. pitch. 6in. × 5in. rolled steel joists support the hydraulic main.

The foul main is 8in. diameter, and has one valve for each bed. It is supported by cast iron stands, and carried round the wall of the retort house with wall brackets. Tar pipes of 3in. diameter are supplied to the underside of each hydraulic pipe, leading to a Dillamore tar tower. A small overhead tank supplies water to the hydraulic main.

Three arches have been constructed, one containing six retorts of the single type, ⌓ shaped, 21in. × 15in. × 10ft. long, the second containing four retorts of the same size, and the third being left empty for the present. The settings are of the Gibbons regenerative type, and at present the bed of six's is at work, and has given satisfactory results, there having been no trouble with stopped ascension pipes in spite of the high heats which have been maintained without variation since the setting was started.

The average yield has been 13,000 cu. ft. per ton of coal, the coal used being South Hetton small and Derbyshire. The fuel consumed averages 28 to 30 per cent. The make per mouthpiece averages 7,000 cu. ft., according to the charges. Advan-

tage is taken of the incline of the ground, so that slope of the furnaces being underneath, as is the case in most works, they are on the ground level at the west end, making the cellar much cooler for the stokers when attending the fires or clinkering, the brick floor of the cellar being well drained. The entrance at this end to the charging floor is by stone steps, with a handrail on both sides. The entrance doors are of corrugated iron, fitted with Hatfield's patent rollers at the top so that they work very easily. The charging section of the retort house floor is provided with $\frac{3}{8}$in. mild steel chequer plates 1ft. × 2ft., supported underneath by 4in. × 3in. rolled steel joists 8ft. $4\frac{1}{2}$in. long. The middle plates immediately in front of the settings are removable for ventilation to the cellar, if required ; the remainder of the floor is paved with blue chequer bricks on 6in. cement concrete.

Retort House and Coal Store.—Both roofs consist of five steel principals, and at the apex of the roof, extending the whole length, an opening is left for a ventilator,composed of 4in × 3in. × $\frac{3}{8}$in. T steel. The principals are formed of 4in. × 3in. × $\frac{3}{8}$in. T steel, with tie rods 3in. × $\frac{3}{8}$in. flat. To the roof are secured $1\frac{3}{4}$in. × $1\frac{3}{4}$in. × $\frac{1}{4}$in. L steel purlins, running the length of both buildings, and spaced at $10\frac{1}{2}$in. centres. The roof is match-boarded and slated and has a tile ridge. The coal store adjoins the retort house, from which it is divided by a wall, having semi-circular arched doorways leading to the three bays of the coal store. It is 43ft. long, 33ft. 6in. wide, and 15ft. high, the walls being of red brickwork 14in. thick. The outer and middle walls of the two buildings have semi-circular openings, rounded off with blue bull-nosed bricks, and two similar openings at each of the gable ends. The coal store is divided into three bays with brick walls on both sides to a distance of 11ft., making an opening in the centre of the store of 11ft. 6in. The ends of the walls have iron channelling to take timber partitions to separate the bays if desired to keep different qualities of coal separate and to reduce the danger of spontaneous combustion. The store when filled will contain a stock of coal sufficient for six months at the present rate of consumption. The coal is easily handled by the stokers, as each doorway is opposite a retort setting.

Engine and Exhauster House.—This is built against the west end of the coal store, and is 25ft. long, 12ft. wide, and 10ft. high. It has a collar-beam roof covered with $4\frac{1}{2}$in × 1in. boards. outside and $\frac{3}{4}$in. match-boarding inside, and slated like the other roofs. The walls are rendered inside with cement, and covered with Blundell's liquid, which dries with a glossy surface and is washable. There is a foundation of concrete 9in. thick and 1ft. 4in. wide under the walls, with one footing course of bricks 14in. wide. The floor is concreted with blue and red tiles set diagonally, giving a clean appearance. The pipe connections to the engines

are covered with iron chequer plates to allow of easy access at any time.

Gas Engines and Exhausters.—The new machinery comprises a $3\frac{1}{2}$ H.P. National gas engine, and an exhauster of the rotary type driven by countershafting, capable of passing 3,000 cu. ft. of gas per hour, supplied by Messrs. Bryan Donkin & Co., of Chesterfield. The old gas engine and exhauster having been thoroughly overhauled, have been refixed in the new engine-house. The old engine is a $3\frac{1}{2}$ H.P. Crossley, which was previously on a combined bedplate with the exhauster, but has now been divided from it, fixed on a separate foundation, and connected by shafting. The exhauster is of the Bryan Donkin rotary type, with a capacity of 1,500 cu. ft per hour. Both exhausters are connected to a governor in the centre, which is provided with an automatic by-pass for use when the governor is not in action.

Sulphate Plant House.—This is opposite the engine-house and on the west end of the retort house, and measures 18ft. 6in. × 18ft. × 15ft. high. The floor of the plant house is of concrete faced with cement. The end wall is provided with a large window, and the sides have two windows and a doorway.

Sulphate Store.—The sulphate store is 18ft. long, 6ft. 6in. wide, and 15ft. high. The floor of the store is of concrete 6in. thick, and is 18in. below the ordinary floor line, being laid with a fall towards the doorway ; it is covered with 8 lb. chemical lead carried up the walls 2ft. above the ordinary floor level, and turned an inch into brickwork. The wooden floor is constructed of 6in. × 2in. joists placed 12in. apart and covered with $1\frac{1}{4}$in. butt-jointed floor boards, and the walls are lined to a height of 6in. with 1in. matchboarding. The store will contain from 16 to 20 tons of sulphate.

Sulphate of Ammonia Plant.—The plant is on the direct system and designed by the Chemical Engineering Company, of Hendon, N.W.

It comprises a vertical steam boiler, supplied by Messrs. Lumby Wood & Son, having a working pressure of 140 lb. per square inch, together with an acid washer, through which the gas passes, containing serrated bars and mother liquor for extracting the ammonia from the gas as it is made. The washer should always contain between 5 per cent. and 1 per cent. of free acid, and never be allowed to become alkaline. An overflow circulating pan fed with sulphuric acid from an overhead tank outside is provided with the washer. The pan has three divisions through which the mother liquor passes, two divisions containing fine cocoanut matting acting as a filter for the heavy tarry matter. The whole of the apparatus, including the valves, is lead lined. The circulation of the liquor through the acid

washer is effected by a small air pump worked by the steam, this also carries the liquor from the washer to the final supply-pan, from whence it is run into the evaporating pan. The latter has, round the inside, a lead steam coil which boils the liquor. The sulphate made is then thrown on a draining table, which has wooden sides and bottom, with a lead lined drain back to the evaporating pan. The salt is finally placed on a drying table, which has a steam coil underneath.

A Wilton still is also worked with this plant, the liquor being supplied from a small overhead tank. The ammoniacal liquor enters the still through a small funnel at the top, and passes through the chambers. The bottom is supplied with wet and dry steam, and lime water is passed over from a lime sift and agitator, entering the still at the base. The ammonia passes from the still through a water-cooled supply to the acid washer, and thus the fixed ammonia is liberated.

The only trouble experienced with the acid washer was when the mother liquor got above 46 degrees Twaddel, when the washer became choked up, and to clear it the writer drained off the liquor in the washer and filled it with water. When the plant was first worked trouble was experienced with discolouration of the salt on account of tarry oil carried forward, but this was overcome by passing the liquor through a filter of silver sand before it entered the evaporator. The plant will probably be a source of revenue when the make of gas increases.

Condenser-Washer.—A Wilton's Reflux Condenser Washer has been erected, and consists of several chambers, with six bubbling trays each working with a seal not exceeding half an inch. The hot gases from the hydraulic main enter the washer at the bottom and pass upwards through all the six trays. The two upper trays are used by the writer as a naphthalene washer by filling them with a suitable solvent, such as paraffin or oil tar. This is done once a week and about two gallons of oil is used, the results being quite satisfactory, not only as regards the solvent but in preventing choking of the washer and removing the last traces of coal tar from the gas.

The middle trays are provided with water cooling pipes, but no reliable information can be given as to the amount of water that is required, as so much depends on local conditions, temperature, etc. During the winter months it would not be necessary to use any water, in fact it is only during the very hot weather that a little would be required, so that the exit gases may be reduced to any desired temperature. The hot gases bubbling through the liquor in the two trays, while raising its temperature, drive off most of the free ammonia, as the condensed liquor is received in the two lower trays from those above. This apparatus is now used in most small works, on

account of its low cost in comparison with condensers and scrubbers, which it equals in efficiency.

Purifiers.—The three new purifiers, 9ft. square and 5ft. deep, were supplied by Messrs. Willey & Co., of Exeter. The valves, six in number, are of the Pickering type, placed below the ground floor and boarded over. The plates are ¾in. thick, with flanges 3½in. wide and ⅞in. thick, secured with ⅝in. bolts. The purifiers are of the luteless type, and occupy what was originally the coal store; the end portion of the house which formerly contained the retort benches being now used as a turning floor for the oxide of iron used for the purifying. A lifting carriage runs on rails on top of the boxes, and is fitted with a screw pulley and wheels on either side. The covers which are on an angle steel frame, 4in. by 3in. by ⅜in. thick, are provided with a 3in. taper plug, with test tap.

Governor.—The 8in. Governor is of the compensating type, made by Messrs. Parkinson & Cowan, and occupies the same position as the previous station governor.

Owing to the abnormal increase in the cost of coal, the price of gas here has been advanced by 5d. per thousand cu. ft., making the charge 4s. 2d. per thousand for cooking and power purposes, and 4s. 4½d. for lighting. The new plant when working at its full capacity will be capable of making 30 million cu. ft. of gas per annum, whereas the present make is about 10 million cu. ft.

PARTICULARS OF CONTRACTS, 1914.

	£	s.	d.
Land, including legal expenses	238	12	0
Buildings, consisting of Retort House, Cellar thereto, Coal Store, Engine and Exhauster House, Sulphate House, and excavating foundations	1,358	15	8
Retort Settings, Chimney, Hydraulic Main, Tar Receiver, and 8in. Foul Mains	755	10	0
Roofs to Retort House and Coal Store...	210	10	0
Supplying and laying 8in. Works connections	148	9	0
Gas Engine, Pumps, and Exhauster, also overhauling and refixing old Gas Engine and Exhauster	213	9	0
Purifiers	390	0	0
Station Governor	75	12	9
Condenser Washer and Sulphate Plant...	375	10	0
Second-hand Boiler purchased for Tar Tank	14	0	0
Vertical Boiler for Sulphate Plant ...	62	0	0
Total Cost ...	£3,842	8	5

6th December, 1915.

NORMAN SCORGIE, M.Inst.C.E., President, in the Chair.

THE MODERN DEVELOPMENT OF WATER POWER.

By Alphonse Steiger, M.Inst.C.E.

The development of water power has entered into quite a new phase since the advent of long-distance power transmission by means of electricity and the application of the electric current to industrial purposes. Whereas formerly hydraulic power plants were installed for a specific purpose, say for driving the machinery in a factory, or a mine, or the pumping engines of some waterworks, and mostly on a small scale, the present tendency is to create large power centres from which the power is distributed over a whole district and supplied to factories or for lighting purposes, for working railways and tramways, or to be used in the most modern industry, that of electro-metallurgical work. The result of this remarkable development has been a complete revolution in the manufacture of water-turbines ; types have changed and the capacity of single units increased from 400 or 500 H.P. (considered large some 20 years ago) to 15,000 and even 20,000 H.P., with a prospect of still larger units in future. Further, the constantly increasing demand for water power has increased its value, so much so that it has become an important object for the investment of capital. It is probably no exaggeration to state that up to the present over 500 million pounds sterling are invested in hydro-electric installations in different parts of the world and we hear constantly of new schemes and undertakings in this direction.

The available water power of Great Britain is variously estimated at from 500,000 to 1 million H.P., the former being a fair basis of calculation, as probably the higher figure would not be available all the year round. In order to show the value of this power, assume that the 500,000 H.P. has to be raised in steam boilers, reckoning that 3 lb. of coal is required to generate one B.H.P. per hour. If the price of coal is 10s. per ton, and taking 300 days of 12 working hours, the quantity of coal required will be $\frac{300 \times 12 \times 500,000 \times 3}{2240} = 2,410,000$ tons, valued at £1,205,000, the latter sum being equivalent to the interest at 5 per cent. on £24,100,000. If it should be asked what can be done with this power, it is only necessary to point to the manner

in which water power has been utilised in countries which are, or soon will be, in direct competition with this country.

With this fact before us, it is to be regretted that progress has so far been very slow in Great Britain, although the large power plants at Foyers and at Kinlochleven should show to be devoid of all foundation the assertion (still frequently made) that there is no water power of any value in this country. This belief, and the indifference resulting from it as regards water power must inevitably have a serious effect on British industry, more especially on the iron and steel industry, in view of the rapidly increasing number of electric furnaces abroad, the products of which are being imported into this country. It may be mentioned that while Germany in 1911 had 26 electric furnaces for producing steel, of an aggregate capacity of 95·8 tons, France 24 electric furnaces of an aggregate capacity of 89 tons, the United States of America 12 electric furnaces of an aggregate capacity of 59 tons, Great Britain had, in the same year only 9 electric furnaces of an aggregate capacity of 27 tons. While, undoubtedly, the modern steam engines, steam turbines, gas, and oil engines are highly economical, the progress made in this direction does not entirely compensate for the increased price of coal, which has doubled during the last 20 years and is likely to increase still further, and it will be found that water is in most cases the cheapest source of power. A prominent English engineer said that by using fuel for generating power we "destroy capital." It is well to keep this truth before us. Water, on the other hand, is indestructible capital and in its eternal circulation, inexhaustible, but as a source of power its use is restricted by topographical, climatic and meteorological conditions, over which we have no control, and further, by the fact that it is a necessity for the existence of the human race in many ways and must, therefore, not be monopolised for one particular purpose.

Although the meteorological conditions differ according to the geographical situation and the topography of a country there is everywhere a certain irregularity in the water supply which is sometimes serious in its consequences in so far as an excess as well as a dearth of water results in the loss of valuable property. Provisions for a greater regularity of the water supply are therefore of the utmost importance, and are found partly in afforestation and partly in storage. Afforestation has been found such an effective means for the prevention, or at least, the diminution of the damage done by floods, that in many countries the Governments have introduced very stringent laws, according to which even private owners of wooded land are not permitted to cut down trees without replanting and eventually increasing the wooded area. Storage works have

been carried out on a large scale for the exclusive purpose of irrigation in tropical countries like India and Egypt ; similar works are now being carried out in Mesopotamia and are contemplated in South Africa and elsewhere. Their value for the cultivation of the adjoining land is incontestable but would be far greater if more foresight had been used in planning them. If, for instance, the large dam at Assuan had been combined with an hydraulic power plant, a large amount of power would now be available for irrigation by pumping in districts farther away from the river. In industrial and more developed countries the question is more one of protection of highly cultivated land against damage by floods and particularly of providing cheap power. Works of this kind were first called into being in France and Switzerland as a consequence of the devastation of large tracts of land by floods. In recent years we find a remarkable development in this direction in Germany, where whole valleys are closed by large dams, with the multiple object of protection against floods, of irrigation, of regulating the flow in rivers for navigation, for the supply of water to towns, and last, but not least, for generating power. It is a significant fact that some of the largest works of this kind are situated in Westphalia, the centre of the German coal-mining industry. Judging from the number of such works already carried out and those in course of construction, the financial results justify the large expenditure on them.

Of special interest is the development of hydraulic power in connection with the navigation of rivers. The value, and in these times of keen competition, the necessity of cheap transit is admitted and its appreciation borne out by the active interest taken by the Governments of several countries on the Continent in a scheme which is in course of realisation.

The author may be forgiven for mentioning this scheme, which is of the utmost importance to his native country, Switzerland. Although Switzerland is often called the country of hotel-keepers, those who know it more intimately know that she has a great and highly developed industry. Being situated in the heart of the European Continent, without direct access to the sea, without producing herself the raw material required for the various industries, and being surrounded by large countries with high tariffs, a wealth of raw material and possessing great seaports, Swiss industries labour under very great difficulties. The Rhine is the only river on which a goods traffic can be carried on to a limited extent as far as Basle. The scheme now is to make the Rhine navigable up to the Lake of Constance. The difference in level between that lake and Basle—a distance of about 80 miles—is 600 feet, including the Falls at Schaffhausen of a height of 66 feet which are already utilised to the extent of

5,000 H.P. by the Swiss Aluminium Company. Owing to the rapid flow navigation above Basle was hitherto impossible. A hydro-electric power plant of a capacity of 18,000 H.P. was erected at Rheinfelden some 17 years ago, the greater part of the power being used for electro-metallurgical and electro-chemical purposes, a further plant with 35,000 H.P. at Augst-Wyhlen, a few miles above Basle, was started about two years ago, a third plant with a capacity of 50,000 H.P. will be started in a few months, and further generating stations are contemplated at Niederschwoerstadt with 44,000 H.P., at Waldshut with 28,000 H.P., and at Eglisau and Rheinau, each with about 18,000 H.P. In all, it is reckoned that about 270,000 H.P. can be obtained between the Lake of Constance and Basle. At the same time the river will be made serviceable as a waterway for vessels capable of carrying about 1,000 tons.

Another and still larger scheme in contemplation is to make the River Rhone navigable in a similar way from the Mediterranean to the Lake of Geneva. It is anticipated that power stations created in this manner and combined with cheap means of transport will become large industrial centres, and it is most probable that the electro-metallurgical industry will be attracted in the first instance.

A pet idea of some people is to obtain useful power from the rise and fall of the tides. No doubt power can be obtained from this source and, technically, there is no difficulty in the way of carrying out such schemes at places where the tides rise to a considerable height, but apart from the fact that the power cannot be constant, the cost of such installations would put them beyond practical possibility from the financial point of view.

It will be seen from the foregoing that water-power may be obtained under widely different conditions. As regards the United Kingdom, the greater part of the water power available is situated in Scotland, Wales and Ireland, mountainous districts with a considerable annual rainfall, which conditions make it possible to develop the power at a quite reasonable capital outlay and under absolutely favourable conditions, by which is meant the possibility of obtaining a fairly constant power during the whole year. This is easily achieved with high falls, when a relatively small volume of water is required per unit of power, which can easily be stored by damming, but it is not possible with low falls, and as these are seldom constant it would appear that they are valueless for the purpose of generating power. There are, indeed, many turbine installations in this country, utilizing low and varying falls, which are exceedingly unsatisfactory, and are possibly one of the causes of prejudice against the utilisation of water power.

These failures have, however, been brought about entirely by want of knowledge and experience on the part of those responsible for these installations. A closer examination of the nature of low and varying falls will show that in almost every case the reduction of the fall is due to an increased volume of water, so that *the available theoretical power is constant within certain limits*, and it is only a question of selecting a suitable type of motor and of adapting it to the varying conditions.

This brings us to the consideration of the different classes and types of water motors. In contra-distinction to steam, or gas power, for which we can arrange the conditions as we desire them, we have to take them in the case of water power as we find them ; we cannot alter them, and they are different in almost every case. To meet all the different conditions and requirements we have a great variety of water motors to select from. They are constructed on various principles : either the water is applied to act by its dead weight, as in overshot, high-breast, and Sagebien water wheels (Fig. 1.), or by pressure, as in pressure engines, or by kinetic energy, as in undershot water-wheels and turbines.

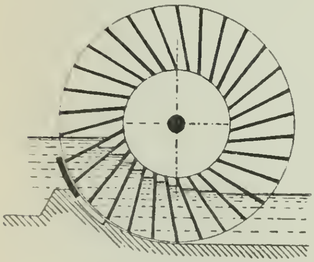


FIG 1.—SAGEBIEN WATER WHEEL.

All motors in which the water acts by its dead weight are highly efficient, yielding, if properly constructed, up to 80 per cent. of the theoretical power, which is the efficiency that may be expected from a very good turbine. It would be misleading to say that more power could be obtained by substituting a turbine for a dead-weight water-motor ; the only advantage would be that power would not be lost in the gearing required by a waterwheel on account of its slow speed. For a new installation, however, a turbine would be preferable on account of greater simplicity and, probably also of cost. Pressure, or piston-engines are very efficient also but their applicability is limited by the necessity of the water being free from sand. Before the advent of the distribution of power by electricity such engines were extensively used in connection with the high-pressure service in towns, for small industries, also for operating cranes, dock-gates, etc.

Water motors which make use of the kinetic energy of water, and in which the water must have attained a certain velocity before it reaches the motor, are the most commonly used. These include all turbines and the undershot waterwheel. Here

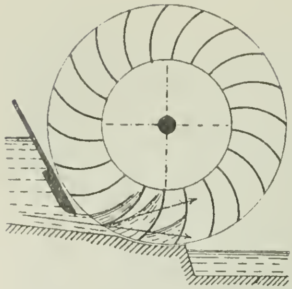


Fig. 2.—Poncelet Water Wheel.

the gain in power owing to greater efficiency is most apparent, for while the efficiency of the ordinary undershot wheel is at most 35 per cent., that of a well designed turbine is at least 75 per cent. and under favourable conditions may be 80 per cent. or even more. The power at a given place may therefore be more than doubled by substituting a good turbine for an undershot wheel. There is, however, one particular type of undershot wheel, the Poncelet wheel (Fig. 2), which, as regards efficiency comes very near the turbines. The essential difference between the Poncelet wheel and the ordinary undershot wheel is that in the latter the kinetic energy is transmitted to the floats of the wheel by "shock," which is avoided in the Poncelet wheel by gradually deviating the water from its course as in a turbine; in fact the Poncelet wheel is an impulse turbine pure and simple. It does excellent work under falls up to about 5 or 6 ft. where there is no backwater, if a high speed is not required and if only a small capital is available. (Fig. 2.)

Classification of turbines.—Turbines are usually classified into impulse-turbines and pressure turbines, and it is sometimes held that impulse turbines are suitable only for high heads and

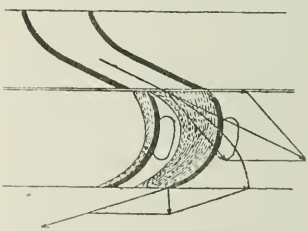


Fig. 3.—Vanes of Impulse Turbine.

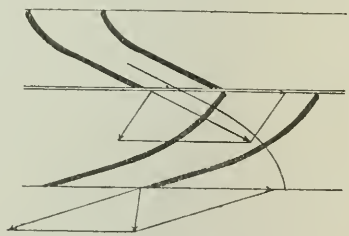


Fig. 4.—Vanes of Pressure Turbine.

pressure turbines only for small heads, but this is not correct; in fact, impulse turbines have been used for heads as low as 3ft. with very good results, and pressure turbines are now frequently adopted for heads of 500ft. and more. The scientific definition of the two classes is that the water enters the vanes of an impulse turbine with the velocity corresponding to the full head, whereas in the case of pressure turbines only a part of the head is applied to generate velocity, while the other part is used to produce pressure within the wheel itself. It is clear from this definition that the selection of a turbine from one class or the other does not depend on the head alone but also on other

factors which will be referred to later on. The difference between the two classes is shown in Figs. 3 and 4, the former showing a section through the vanes of a impulse-turbine and the latter a section through the vanes of a pressure turbine. In both diagrams the absolute path of the water through the vanes is shown as well as the relative values of the velocity of entrance, velocity of rotation, and velocity of discharge. The absolute velocity of discharge represents unutilized energy and must therefore be made as small as possible. This is achieved by making the angle at the discharge end small. The passages of the pressure turbines must be entirely filled by the water as otherwise no pressure could be produced.

The advantage of the impulse turbine is that its hydraulic efficiency is constant, *i.e.*, it is independent of the volume of water admitted to the wheel and it matters not whether the water impinges on the whole or only on a part of the periphery of the wheel, and the water does not generally fill the buckets during its passage. This type is, therefore, eminently suitable for a varying water supply. The wheel must, however, run clear of the tail-water, a condition which can seldom be fulfilled in the case of low falls where the tail-water is liable to rise with an excess of water, but if the vanes are designed as shown in Fig. 5 so that the passages are entirely filled with water, the efficiency is not affected by submersion. The efficiency of impulse turbines is, however, considerably influenced by the speed, and if they are running at a speed different from that due to the head, their efficiency falls off. Wheels provided with buckets as shown in Fig. 5, may be considered as the connecting link between impulse and pressure-turbines.

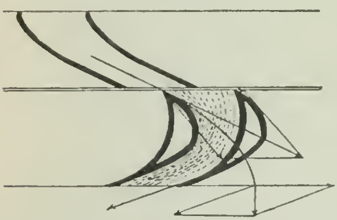


FIG. 5.—VANES OF INTERMEDIATE TYPE TURBINE.

The latter class, sometimes also called reaction-turbines, lend themselves admirably to the utilization of low falls. On account of the necessity of the buckets being entirely filled with water, their diameter may be taken smaller than that of impulse turbines for the same fall and power ; their speed is therefore higher, which is a great advantage. Another advantage is that, while impulse turbines must be placed as near to the tail-water as possible, pressure turbines may be placed in any position between head-water level and tail-water level, provided the height of suction does not exceed from 20 to 25ft., and provided there is a sufficient body of water above the turbine to prevent air from being drawn into it. The turbine must in

that case be connected to the tail-race by means of an airtight draft tube, either of iron or concrete. The part of the total head below the turbine acts then by suction.

Turbines of either class may be designed as parallel-flow turbines, or as radial inward-flow or radial outward-flow turbines. From the point of view of efficiency alone, the first two are about equal, but the loss by unutilized energy is much greater in radial outward-flow turbines.

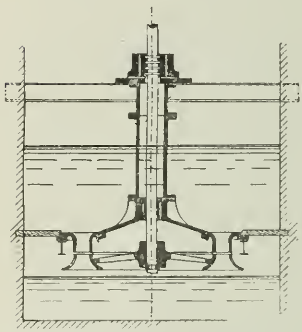


FIG. 6.—GERARD TURBINE WITH VERTICAL SHAFT.

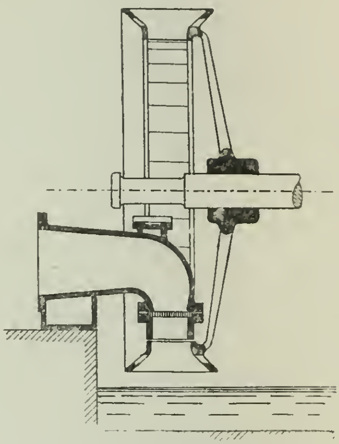


FIG. 7.—GIRARD TURBINE WITH HORIZONTAL SHAFT.

Types of impulse turbines are shown in Figs. 6, 7, 8 and 9. Fig. 6 represents the ordinary Girard turbine with vertical shaft, as used for low falls ; Fig. 7, a Girard turbine with horizontal shaft, suitable for high heads with a fairly large water supply ; Fig. 8, the well-known Pelton wheel as now commonly used for high heads and a relatively small volume of water. The tangential wheel shown in Fig. 9 is a radial inward-flow turbine most suitable for medium and high heads with a large water supply.

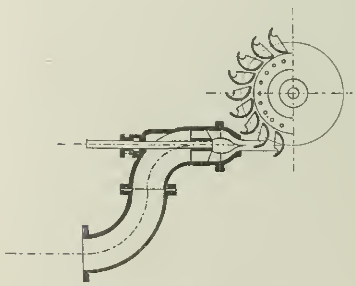


FIG. 8.—PELTON WHEEL.

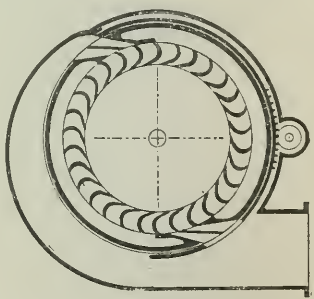


FIG. 9.—TANGENTIAL WHEEL.

Pressure turbines.—Pressure turbines of the radial outward flow type are the invention of Fourneyron, but are better known in this country as McAdam turbines. Such a wheel for a low fall is shown in Fig. 10. Curiously enough, this type was adopted for the 5,000 H.P. units first installed at the Niagara Falls.

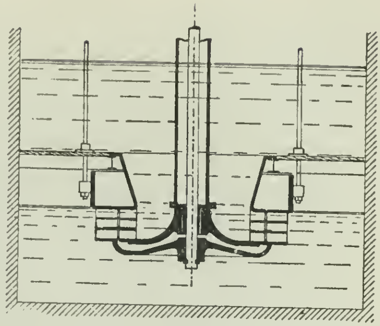


FIG. 10.—FOURNEYRON TURBINE.

Admirably adapted to low and varying heads with a varying water supply is the parallel flow or Jonval turbine, which has been adopted in a large number of cases to drive flour mills in this country, invariably with highly satisfactory results. In order to obtain a good efficiency under the varying conditions the wheel is subdivided into two or three concentric rows of buckets, each row practically representing a complete turbine in itself. The outer row is of such dimensions that it will pass the minimum quantity of water, which generally corresponds with the maximum head, while the inner row or rows of buckets will be capable of passing an increased volume when the head is reduced, whereby the power is kept constant. It will be observed that, when the outer row of buckets alone is used with the maximum head, the diameter on which the water acts is larger than when the water is also admitted to the inner row under a reduced head, when the velocity of the water is obviously smaller. In this way the speed of the turbine is also kept constant. (Fig. 11.)

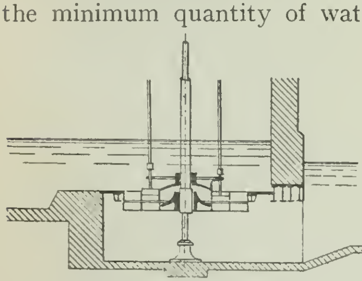


FIG. 11.—JONVAL TURBINE.

A good instance of an installation of a Jonval turbine under varying conditions is that at Strencham Mills near Worcester, giving 40 H.P. under a minimum fall of 2ft., which is probably the smallest fall ever utilized by a turbine. The maximum head with the normal summer supply is 4ft. 3in., but after a heavy rainfall, and during the winter months it is frequently reduced for long periods to 2ft. and even less. The question was to make the best possible use of these varying conditions. The wheel consists of two concentric rows of buckets, the outer one being capable of passing 6,700 cu. ft. of water per min. with a head of

4ft. 5in., and developing 40 H.P. When the fall is reduced to 2ft., 14,000 cu. ft. are required for 40 H.P., but the outer row will then pass only 4,500 cu. ft. per min., the inner row must, therefore, be capable of passing 9,500 cu. ft. per min. The outside diameter of this wheel is 14ft. and its constant speed is 14 r.p.m. With a light load this turbine drove the mill even when the fall was reduced to 18in.

Considered from the point of view of efficiency alone, the Jonval turbine is eminently suitable for the conditions described, but its great drawback is that it does not lend itself easily to automatic regulation such as is required in installations intended for the generation of electricity. For this reason it has been superseded by the Francis turbine, the prototype of the radial inward-flow turbine.

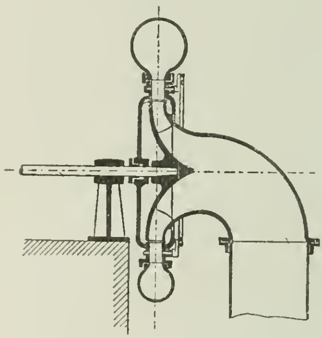


FIG. 12.—INWARD FLOW TURBINE.

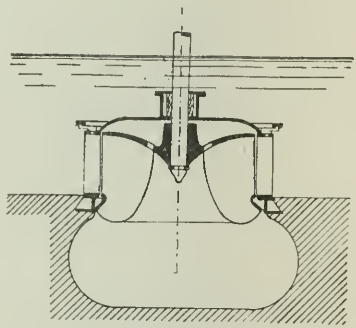


FIG. 13.—MIXED FLOW TURBINE.

There are a great variety of designs of the latter type, differing principally in the proportions of the diameter and width, and in the construction of the regulating device. Originally, it was an inward-flow turbine pure and simple, the water entering and being discharged in a radial direction. This required a relatively large diameter and the speed was consequently small. Partly with the object of producing cheap turbines, and partly to satisfy the demands of electrical engineers for a high speed, the diameter of the wheels was gradually reduced, the width increased and the vanes extended in an axial direction and provided with scoop-shaped ends, the water leaving them in a more or less axial direction. In this way the mixed-flow turbine was evolved from the pure inward-flow turbine. Fig. 12 shows a pure inward-flow turbine for medium or high heads, and Fig. 13 a mixed-flow turbine for a low head. A few first-class makers have succeeded in obtaining, under specially favourable conditions, an efficiency of 84 to 85 per cent., but it would be absurd to deduce from this that such results would be obtained

in all cases. It is important to point out that a high speed relative to the fall can only be obtained at the expense of efficiency, more particularly at part gate, *i.e.*, with a reduced volume of water. High speed turbines are, therefore, uneconomical where the water supply is sometimes reduced for a considerable time. If the loss of power on account of inferior efficiency, whether at full gate or at part gate, were considered more often in the light of £ s. d., and capitalised, many of the turbines largely advertised under high sounding names as the most economical, would soon disappear from the market.

The efficiency, generally, of a turbine depends on the proper dimensions and the correct and scientific design, but at part gate it is further influenced by the system of regulation of which there are three :—the cylinder gate, the register-gate, and the movable guide blades. The cylinder gate (Fig. 14) consists of a

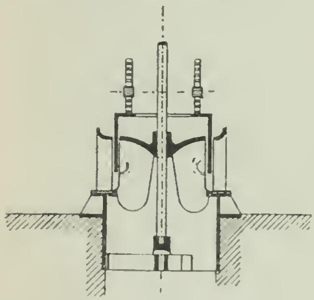


FIG. 14.—CYLINDER GATE.

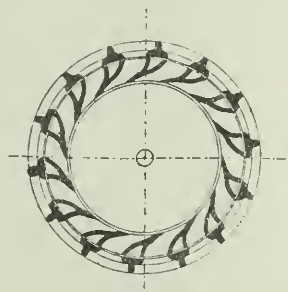


FIG. 15.—OUTSIDE REGISTER GATE.

cylinder placed between the guide wheel and the runner which is moved parallel to the axis by means of racks and pinions, whereby the width of the opening through which water is admitted to the wheel is altered. It is clear from the illustration that eddies must be produced when the gate is partly open, which are detrimental to the efficiency of the turbine. In the Hercules turbine transverse partitions are provided to prevent the formation of eddies at the entrance but they are hardly effective.

The register gate is also cylindrical, but it is made to turn on its axis. It may be placed either on the outside (Fig. 15), or on the inside (Fig. 16), of the guide wheel. The latter is preferable, but it has often been a source of great trouble where the water contains sand or other solids.

The best method of regulation of radial and mixed-flow turbines is undoubtedly that by means of movable guide blades. As shown in section in Fig. 17, the guide-blades are hinged on pins which pass through the walls of the guide wheel and carry cranks or eccentrics which are connected to a ring by means of

which all the guide blades are moved simultaneously. In some turbines the attachment for moving the guide blades is inside and seriously obstructs the passage of the water.

FIG. 16.—INSIDE REGISTER GATE.

FIG. 17.—MOVABLE GUIDE BLADES.

Although this mode of regulation of pressure turbines is not theoretically correct, in so far as the relation between the areas of the guide passages and of the runner, by which the degree of re-action is fixed, is disturbed, quite satisfactory part gate results are obtained from carefully designed turbines. Generally, the greater the head applied for producing velocity, or the smaller the head applied for producing pressure, the better the efficiency of the turbine when working at part gate.

Fig. 18 shows the curves of efficiency at different gate openings of a Pelton wheel, a Francis turbine designed for a high efficiency under varying conditions, and a modern "high speed" Francis turbine. It will be seen that, while the efficiency of the Pelton wheel is practically constant for a very wide range of gate openings, that of the high-efficiency Francis turbine is also high down to half gate, and still quite satisfactory at $\frac{1}{3}$ gate, while the efficiency of the high-speed turbine decreases rapidly with the reduced gate opening. The space marked on hatched lines represents the loss of power resulting from the disregard of varying conditions when choosing a turbine. A purchaser will do well to consider what effect this loss would have on his revenue.

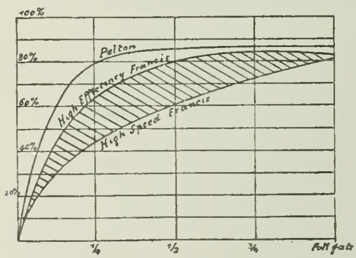


FIG. 18.—EFFICIENCY CURVES OF PELTON WHEEL AND FRANCIS TURBINES.

Application of Turbines to various conditions.—After having considered the conditions under which water power may be obtained, and the different classes and types of water motors, the application of the latter is perhaps best explained by describing some typical modern turbine installations, beginning with low heads.

Turbines utilizing heads up to 6 or 7ft. are invariably fixed on a vertical shaft. The whole weight of the parts fixed on the turbine shaft revolves on a footstep which may be placed either below or above the turbine. In the first case its lubrication is mostly left to the water. Apart from the fact that water is a very bad lubricant, the inaccessibility of the most delicate part of the turbine is very objectionable. Moreover, the lignum vitæ bearing is generally carried by a bridge or cross piece fixed in the draft tube and thus forms a serious obstruction to the free discharge of water. In modern practice the footstep is placed above the turbine and submerged in oil. Fig. 19 gives an idea of an overhead footstep very commonly used for turbines of moderate power.

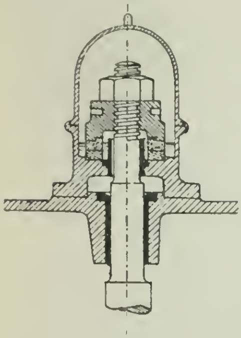


FIG. 19.—STEP BEARING.

Ball thrust bearings have so far not been extensively used in connection with turbines, although they have proved highly satisfactory in vertical high-lift turbine pumps. The conditions here are, however, different. Turbine-pumps run at a very high speed and the thrust to be taken up is not very great, while in the case of water-turbines the speed is relatively small, but the weight of the revolving masses is very great. Ball thrust bearings were used for three turbines at the Portland Cement works at Aarau, in Switzerland, each turbine giving 740 B.H.P.* under a head of 6ft. 5in. The turbine wheel (shown on the screen) has a diameter of 12ft. 6in., and is 5ft. 6in. wide and runs at 28½ r.p.m. The wheels are cast in one piece and each weighs 10 tons. The total load on the ball thrust bearing, consisting of the turbine wheel, the shaft, the large bevel wheel on top and the water pressure, is 50 tons. The thrust bearings have proved to be very satisfactory in this case.

It is quite an exception that so large a power is produced by one single wheel under such a low head, and is accounted for by the fact that a slow speed was admissible in this case. Where a high speed, or large units of power, are required with a low head, as in the case of power installations utilizing large rivers, two or more wheels are fixed on a common shaft, either vertical or horizontal.

On the screen is shown one of 11 units with wheels fixed on a vertical shaft, installed at the power station at Beznau, on the River Aare. The fall varies from 10 to 19ft.; each unit is designed to give from 1,000 to 1,200 b.h.p.,† and the speed is 66.6 r.p.m. In order to utilize the available power as economically as possible under such varying conditions, six units have

* See Fig. 22A (facing p. 246). † See Fig. 22B (facing p. 246).

been designed to give the best efficiency with the maximum head and the minimum water supply, and five units with the minimum head during floods. The upper and the middle wheel discharge the water into a common draft tube, formed in concrete, whereby the water pressure from these two wheels is balanced. The total load transmitted on to the footstep is 45 tons. This load is reduced by balancing, by 12·7 tons when the head is 11ft., and by 23·7 tons when the fall is 19ft. The step bearings, of 22in. diameter, are situated in a gallery below the generators. The footstep proper is contained in a casing filled with oil, kept cool by a coil through which water is circulated. The oil is forced into the step bearing with a pressure of 360 lb. per sq. in. The whole weight thus revolves practically on a film of oil and the loss of power by friction is trifling. In large installations like this a special pumping plant is provided for producing the pressure necessary for the hydraulic governors and for the forced lubrication of the footsteps of the turbines and generators.

A horizontal arrangement of multiple turbines is illustrated in Fig. 20 and has been adopted for the power installations at Augst-Wyhlen, near Basle, already referred to in connection with the navigation scheme of the Rhine. The fall, created by the erection of a sluice weir across the river, varies from 18 to 27½ft., and each unit is capable of producing from 2,200 to 3,000 B.H.P. To obtain a speed of 107 r.p.m., the volume of water required for that capacity, maximum 115,000 cu. ft. per min., is divided between four wheels on one shaft, the wheel pits being placed in the river and separated from the engine house by a thick wall. The guide wheel nearest the wall is mounted on a large cast iron wall-plate which hermetically closes the opening of the shaft. Access to the bearings of the turbine shaft is obtained through galleries in the foundations.

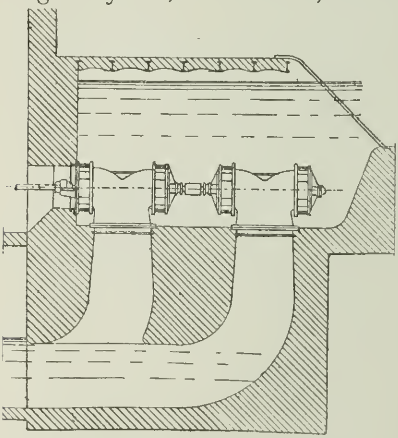


Fig. 20.—Quadruple Horizontal Turbine.

Opinions differ as to the superiority of the vertical over the horizontal arrangement. The first requires a smaller area for the foundations and power house, and allows an almost complete balancing of the load on the footstep, thus eliminating

friction, but a saving in area is not necessarily identical with saving of cost. Special local conditions, such as the nature of the ground, will, in most cases, be the determining factor for the adoption of the vertical or the horizontal arrangement.

Figs. 21 to 25 show various arrangements of Francis turbines, with vertical and horizontal shafts, single and double, in open water-chambers. In some of them the draft tubes are of con-

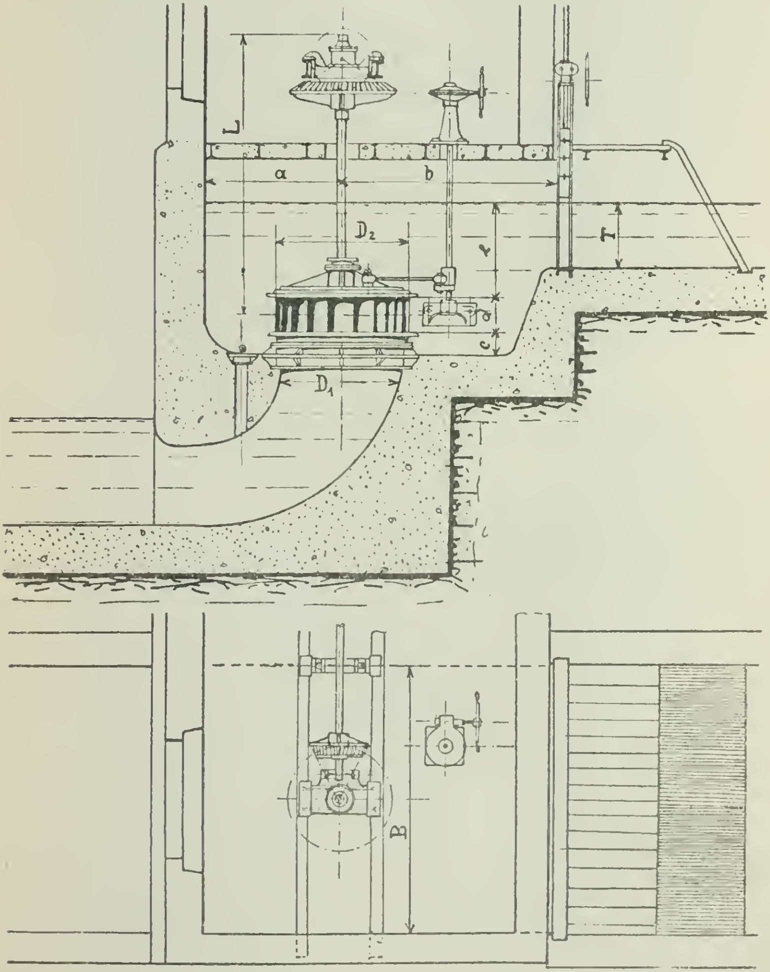


Fig. 21.—Single Francis Turbine, with Vertical Shaft and Concre- Suction Tube.

crete, which is generally preferred because the direction of flow is changed gradually from the vertical to the horizontal. The area of the draft tubes should gradually increase towards the lower end so as to reduce the velocity of discharge, which represents a gain in efficiency of the installation.

With heads above 30ft., open turbine pits are seldom used. The turbines are enclosed in casings to which the water is admitted through pipes. The turbine may be a single one (Figs. 26 and 26a), or double, discharging through two draft tubes (Fig. 27), or two wheels may be fixed on a common shaft, discharging the water into a common draft tube between them (Fig. 28). The latter arrangement is preferable because the wheels can be placed nearer the bearings, and will, therefore, run steadier and the stuffing boxes on the suction side (which are always liable to let in air and destroy the vacuum in the draft tube) are not required. The casing for a single wheel is generally of a spiral shape, and for two wheels cylindrical. The spiral casing gives a better emission of water to the guide wheel and tends to increase the efficiency.

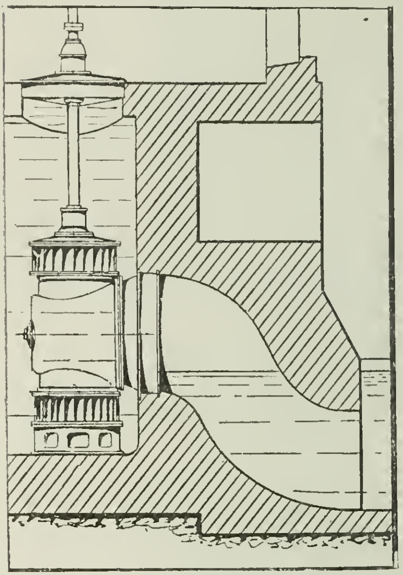
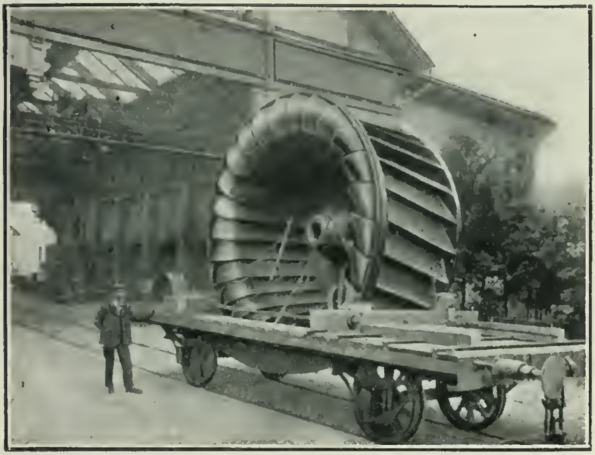


FIG. 22.—DOUBLE TURBINE, VERTICAL SHAFT WITH CONCRETE DRAFT-TUBE.

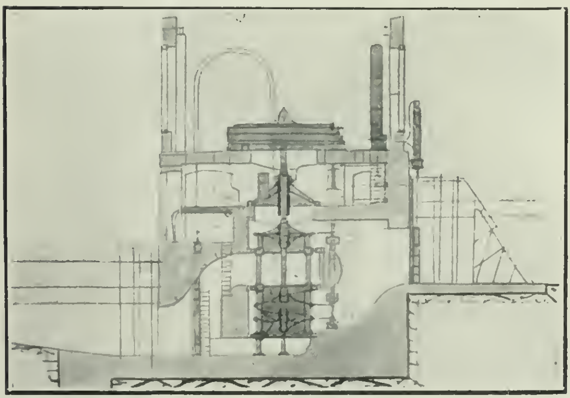
A double spiral turbine is shown on the screen. It is one of five turbines installed at Vigeland, Norway, for the Anglo-Norwegian Aluminium Company. The output is 3,000 b.h.p.,* with a net fall of 55ft. and the speed is 220 r.p.m.

It has been mentioned that pressure turbines may be, and are, used for very high heads, but there is a limit. As the volume of water required, even for a relatively large power, is obviously small, the diameter of the turbine, the passages of which must be entirely filled, will be small, and, consequently, the speed very high. The question whether a high fall is to be utilized by a pressure turbine or by an impulse turbine is therefore, determined by the power required from a unit and by its speed. To illustrate this, we will assume that the Victoria Falls are to be utilized. The height of these Falls is 420ft.

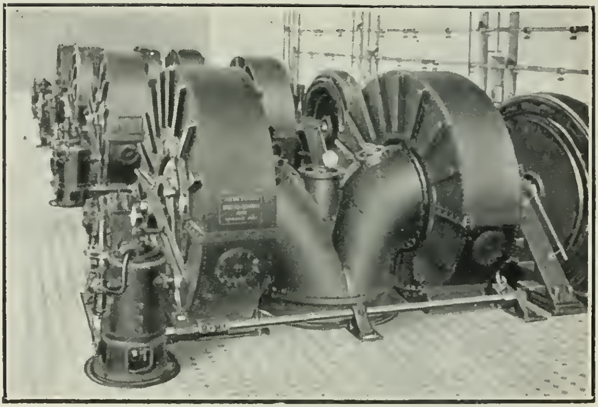
* See Fig. 23A (facing p. 247).



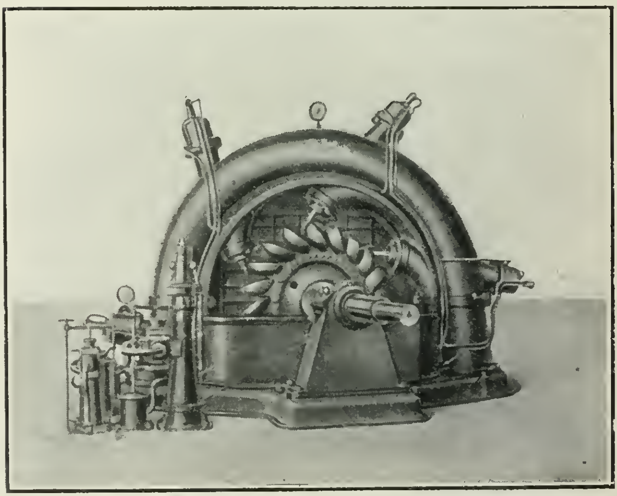
Turbine Wheel for 740 B.H.P. Fall 6 ft. 5 in.
Fig. 22a (*see p.* 245).



Triple Francis Turbine at Beznau. 1,200 H.P.
Fig. 22b (*see p.* 245).



Double Spiral Turbine. 3,000 H.P.
Fig. 23a (*see p.* 248).



Pelton Wheel with 6 nozzles.
Fig. 23b (*see p.* 256).

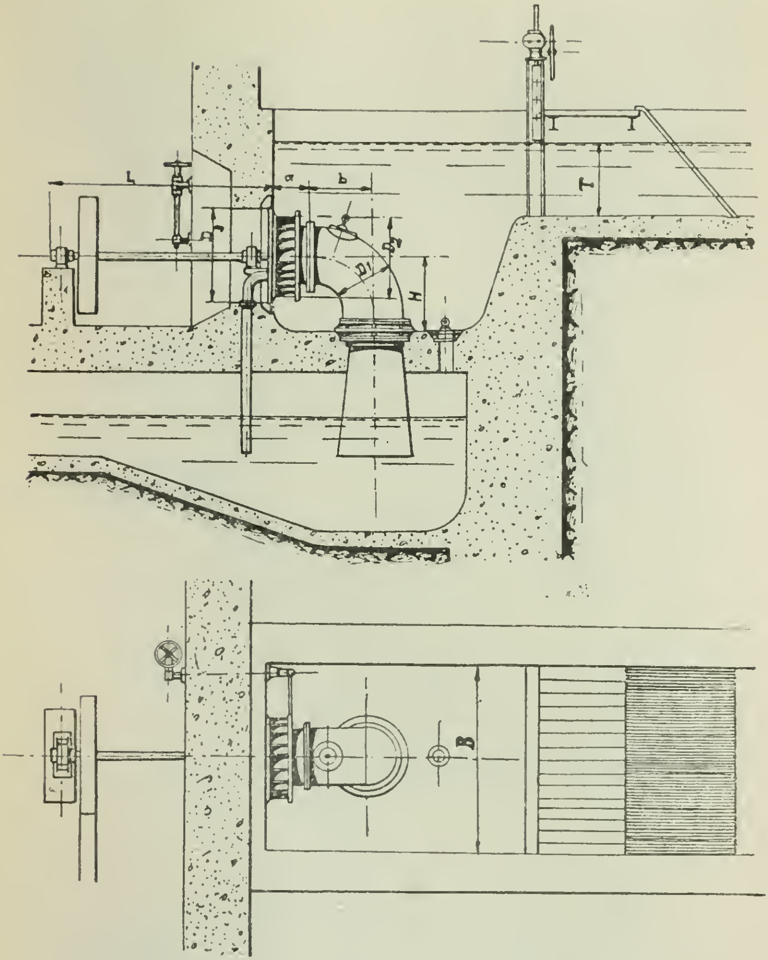


FIG. 23.—SINGLE FRANCIS TURBINE, WITH HORIZONTAL SHAFT AND IRON SUCTION TUBE.

If units of say 3,000 b.h.p. were adopted, the smallest speed at which a satisfactory efficiency could be obtained from a Francis turbine of that power would be about 550 r.p.m. If this speed were considered excessive for units of 3,000 b.h.p., then an impulse turbine would have to be chosen or, alternatively, the power of the units would have to be increased. As the total power available at Victoria Falls is several hundred thousand h.p., units of the largest practicable capacity, say from 20,000

to 30,000 b.h.p., would be adopted for which a speed of 300 r.p.m. would probably be admissible.

Impulse Turbines.—We are not bound by such limits in choosing the speed if we adopt impulse turbines for high heads. In these, each jet acts independently and there is, in the strict sense of the word, no relation between the quantity of water and the diameter of an impulse turbine.

The turbine of this class, now almost universally used, is known as the Pelton wheel. It consists of a number of single

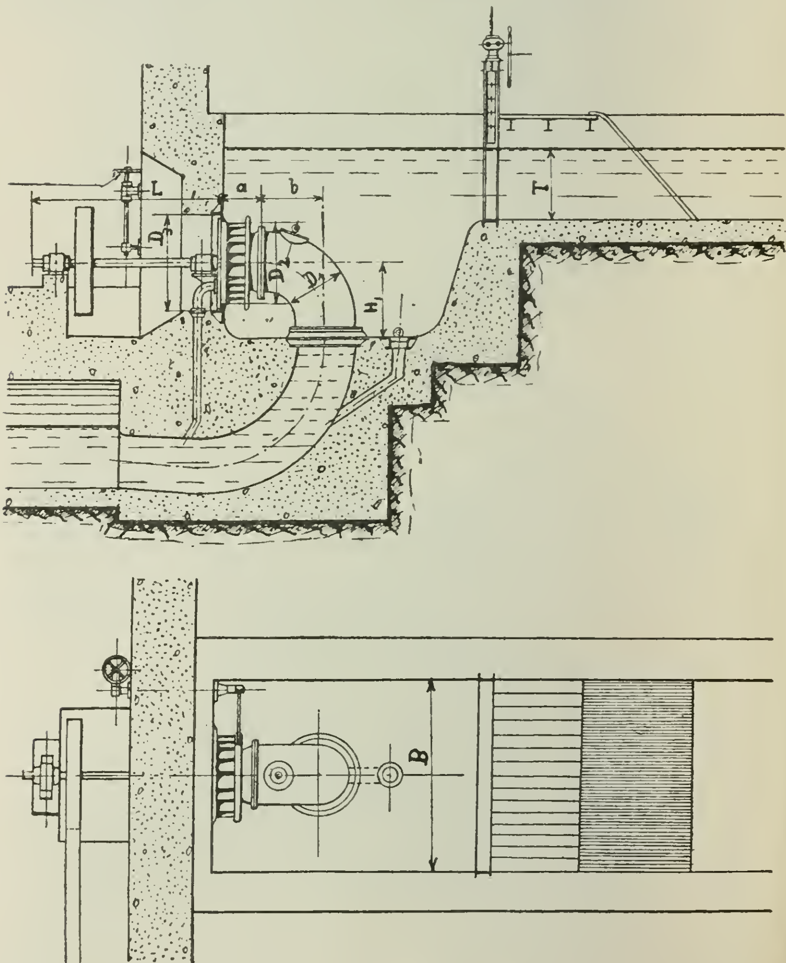


Fig. 4.—Single Francis Turbine with Horizontal Shaft and Concrete Suction Tube.

or double spoon-shaped buckets, bolted on to a disc fixed on the shaft and rotating in a watertight casing. The buckets are made either of cast iron, cast steel, or bronze. They are often ground or highly polished on the concave surface to minimize the friction and thus increase the efficiency. There are a large number of different designs of buckets, according to the ideas

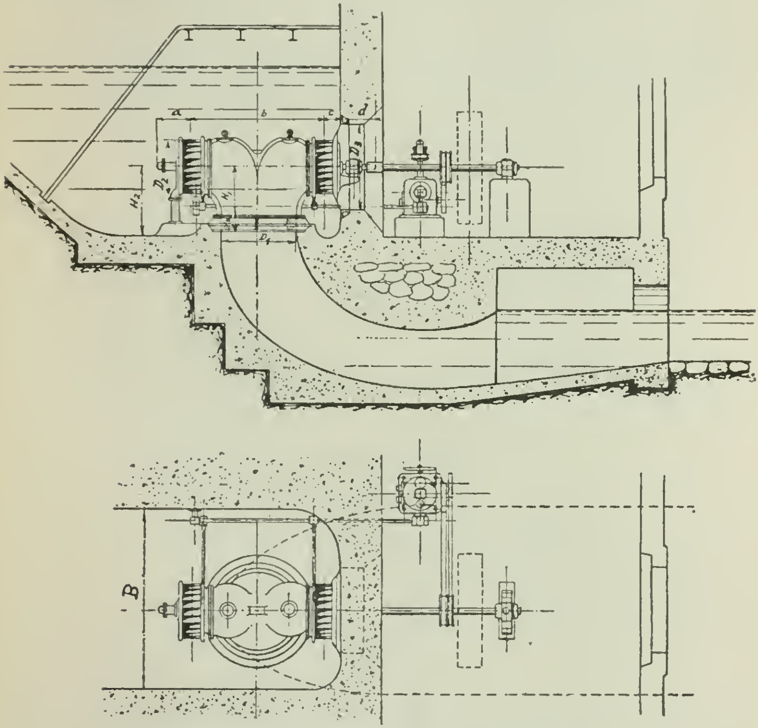


FIG. 25.—DOUBLE FRANCIS TURBINE WITH HORIZONTAL SHAFT AND CONCRETE SUCTION TUBE.

of the makers. The Pelton bucket is characterised by its more or less rectangular shape, with a sharp-edged flat lip in front and an edge across which divides the jet in halves. The rather abrupt corners found in some such buckets are a great drawback in so far as they must produce shock and eddies which, as has recently been discovered, cause a dissociation of oxygen from the water, thus corroding the metal very quickly. The rapid destruction of the buckets in some cases was at first thought to be due to sand but was subsequently traced to the above cause.

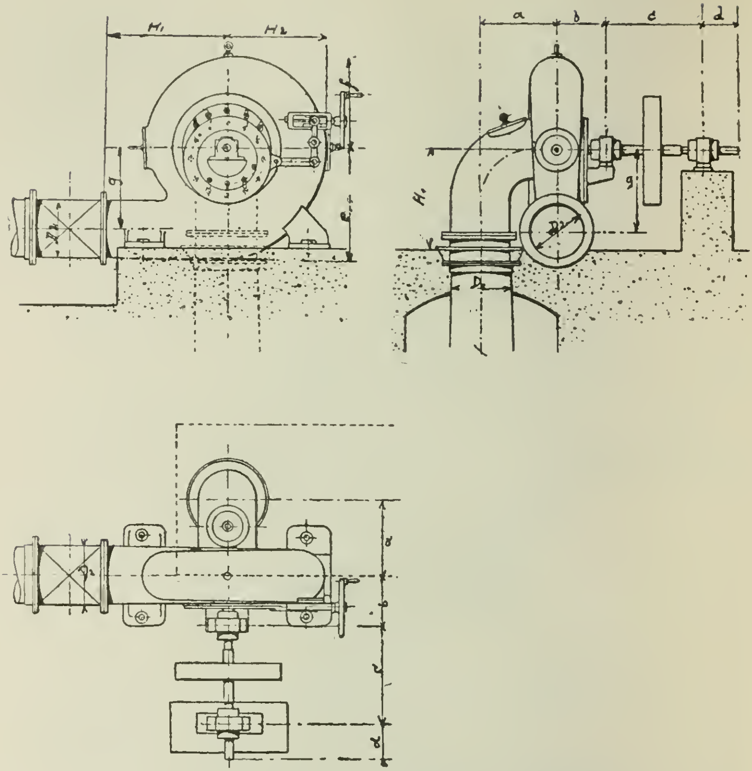


FIG. 26.—SINGLE SPIRAL TURBINE, WITHOUT STUFFING BOX ON SUCTION BEND.

Doble buckets are of elliptical shape, with a recess in front and also an edge which divides the jet. No eddies can be formed in these buckets, nor shock produced; they are, therefore, more durable and also more efficient than the Pelton buckets. The "Hug" bucket is little known, but is of excellent design. It is shown in Fig. 31. Tests made with a wheel of Hug's design have proved it to be as efficient as wheels with Doble buckets. The shape of the buckets has little influence on the efficiency as long as the water can impinge without shock, is gently deflected from its original course and discharged from the wheel without impediment and as nearly as possible in a lateral direction. It is curious to note that some makers seem to hold the opinion that the water should be discharged as nearly as possible in a direction opposite to that of the jet. This has

misled them into making the housing too narrow, with the result that the water, after having been discharged, rebounds on to the wheel and, thus reduces the efficiency.

The most important part next to the buckets is the nozzle. It is either rectangular or circular in section, the latter shape being now generally preferred on account of its simplicity of regulation. This is accomplished by pushing a spear or needle,

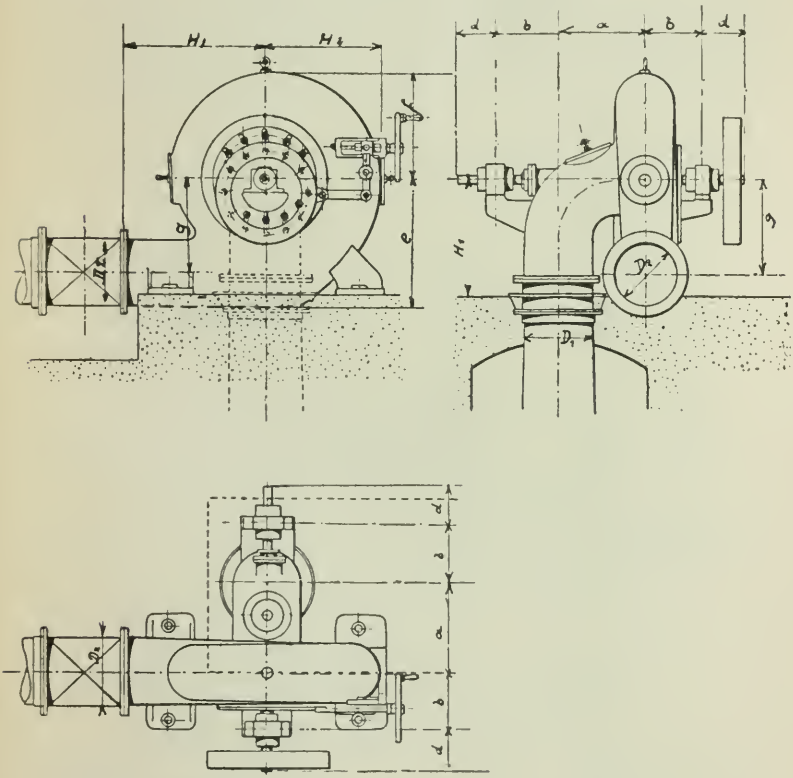


Fig. 26a.—Single Spiral Turbine, *with* Stuffing-Box on Suction Bend.

provided with a cone-shaped plug into the mouthpiece of the nozzle (Fig. 8). The rectangular nozzle is regulated by a hinged tongue or gate as shown in Fig. 32 and 33. Sometimes Pelton wheels are found without any means of reducing the area of the nozzle, the regulation being effected either by a sluice valve, or by the deflection of the nozzle from its normal position. Both methods are objectionable, the first because it produces

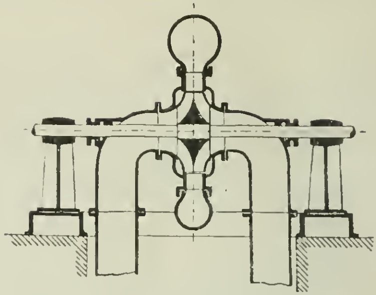


FIG. 27.—DOUBLE SPIRAL TURBINE WITH TWO DRAFT TUBES.

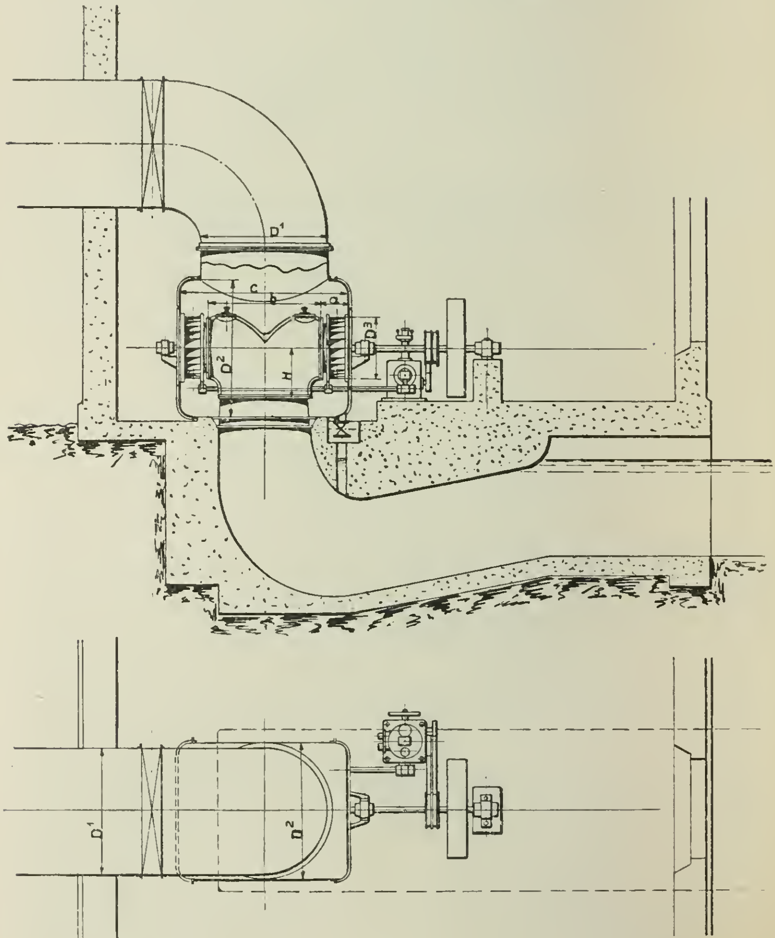


FIG. 28.—DOUBLE FRANCIS TURBINE, HORIZONTAL SHAFT AND CYLINDRICAL CASING.

a loss of head, and the second because it causes the jet to impinge at an improper angle, producing shock and more rapid wear of the buckets ; moreover, the movable joint is liable to become leaky and, in addition, it is wasteful.

The nozzle of a Pelton wheel may be large if the diameter of the wheel is large. The Pelton wheel of 16,000 B.H.P., erected at the Loentch Electricity Works for a head of 1,150ft., is provided with two nozzles of 8in. diameter each. The diameter of the wheel is 7ft., giving a speed of 300 r.p.m. Incidentally, it may be mentioned that this wheel, like the 6,500 H.P. wheels at the same place, is fixed direct on to the free shaft end of the generator.

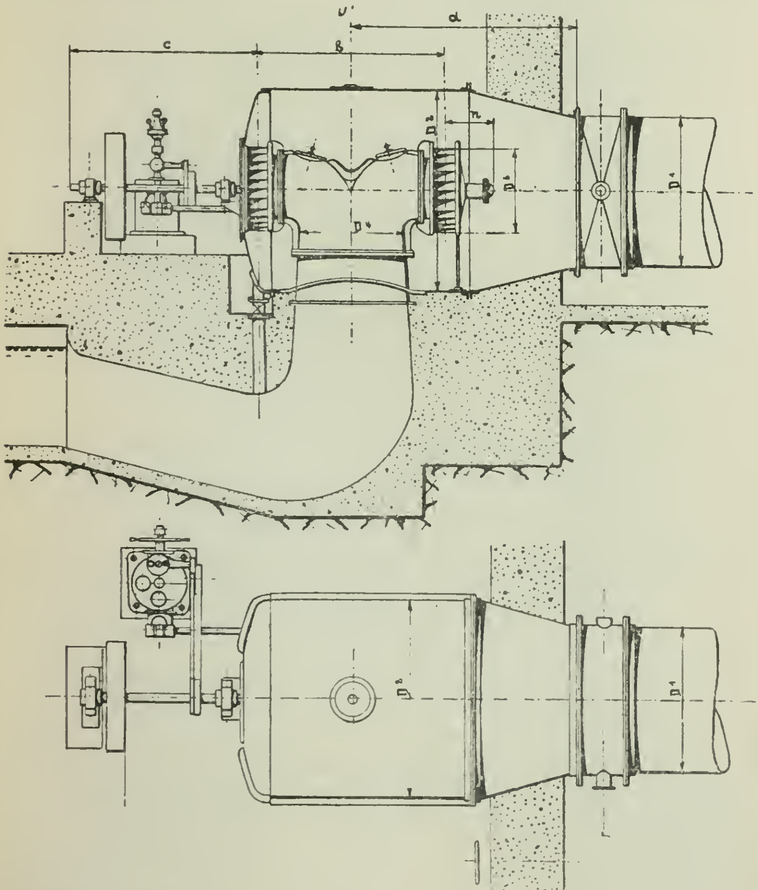


FIG. 28A.—DOUBLE FRANCIS TURBINE WITH HORIZONTAL SHAFT, AXIAL ADMISSION.

If it be necessary to divide the water between several nozzles, these may be directed on to one wheel, or to two wheels fixed on a common shaft. The single wheel is preferable from every point of view cost, saving of space, and lastly of efficiency.

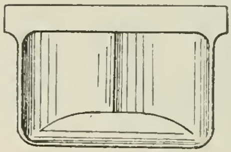


Fig. 29.—Pelton Bucket.

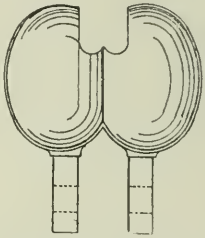


Fig. 30.—Doble Bucket.

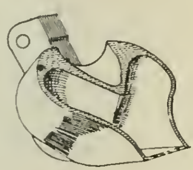


Fig. 31.—Hug Bucket.

A Pelton wheel with six nozzles is shown on the screen.* This was supplied by the author for the temporary installation at Kinlochleven, for the British Aluminium Company. It was calculated to give 3,000 b.h.p. with a head of 380ft., and to run at 300 r.p.m. The six nozzles are placed at equal distances in the spiral casing which surrounds the wheel and through which the water is admitted to the latter. In order to prevent obstruction of the jets by the water discharged from other jets, deflectors or baffle plates are fixed in the spherical side walls of the housing which guide the water into the pit leading to the tail race.

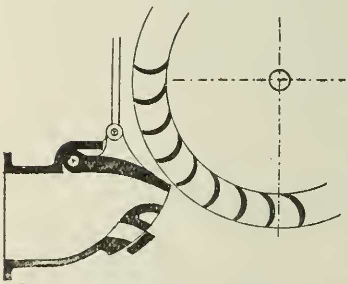


Fig. 32.—Square Nozzle with Hinged Tongue.

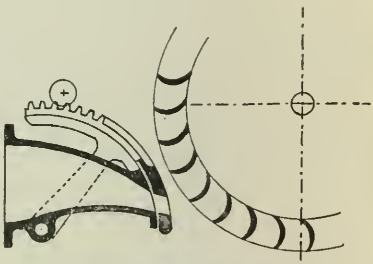


Fig. 33.—Square Nozzle witth Hinged Gate.

The arrangement of two Pelton wheels on one common shaft would seem unavoidable where the nozzle area becomes large, but where a Francis turbine would run at too high a speed, a single Girard turbine, or a tangential wheel, fixed on either a horizontal or a vertical shaft would, in the author's opinion, be better and cheaper. Pelton wheels have become the fashion

* See Fig. 23b (facing p. 247).

for high heads, but there is no reason whatever why another type should not be employed if, in a given case, it offers greater advantages.

Under the heading " Pressure turbines " a fall of two feet has been mentioned as the lowest fall which it is practicable for a turbine to utilize. For impulse turbines the question is, which is the highest fall which can be utilized by one wheel ? It is, indeed, interesting to observe the progress made in recent years. Two decades ago the most experienced maker of Pelton wheels would have declared it impossible or, at least very risky, to utilize a fall of 2,000ft. in one stage ; at present there are several well-known instances of installations where such heads are used with complete success, both in America and in Europe, and heads of even 3,000ft. are now unhesitatingly used. One of these is the installation at Arniberg, on the Gothard Railway, of several units of 3,000 b.h.p., under a head of 2,800ft. One of these units is shown in Fig. 34, and will be described later on in connection with the hydraulic governor. An installation with a still higher fall, namely 5,000 ft., is now in course of construction and the author's opinion has recently been asked as to the possibility of utilizing a fall of 6,000ft. The chief difficulties to overcome in utilizing such high falls consist in finding a material which will withstand with absolute safety the strain to which a wheel rotating at a peripheral velocity of about 260ft. per second is exposed, to produce pipes of adequate strength and to govern such wheels with perfect accuracy. Thanks mainly to electro-metallurgy, material of the highest quality is now available, and hydraulic governors have been brought to such a state of perfection that that part of the problem may also be considered as successfully solved.

Governing.—The method of automatically regulating the speed of turbines has undergone a complete change. Excellent as many of the old mechanical governors were, their action was much too slow for modern requirements. Thus the hydraulic governor has been called into being, viz., a governor in which hydraulic pressure is used to move the regulating mechanism of the turbine. The hydraulic pressure may be obtained direct from the water if the head is high, otherwise pumps are used and the liquid put under pressure is oil. Water taken from the penstock must pass through a filter before it is admitted to the regulating valve. In modern practice the oil pressure-governor is preferred even in connection with Pelton wheels utilizing very high heads. Such a governor is shown in Fig. 35. It consists mainly of a centrifugal pendulum, a regulating valve, a hydraulic cylinder with piston, called the servomotor, the relay mechanism and a rotary oil pump. The action is as follows : Any slight change in position of the pendulum, following a change of load, is

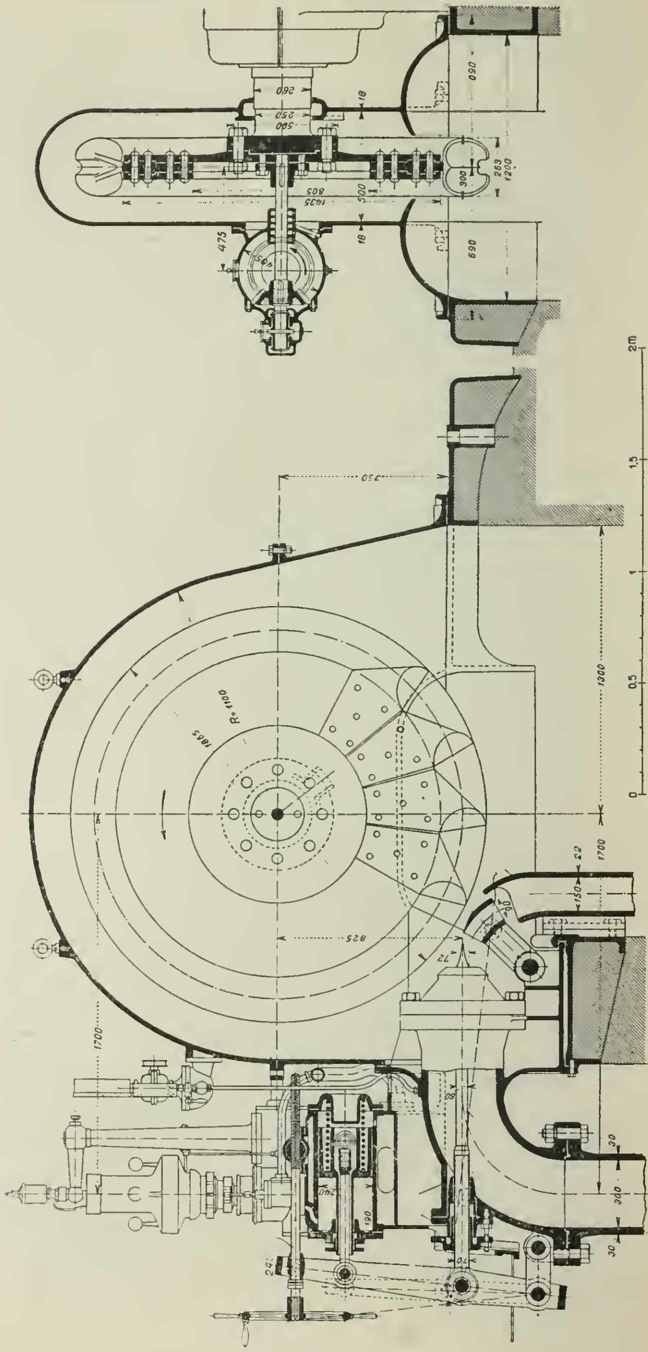


Fig. 34.—Cross Section of 3,000 h.p. Pelton Wheel at Arniberg.

immediately transmitted to the regulating valve V., by means of the lever H. By raising or lowering the regulating valve a connection is established between the pump and the pressure cylinder, when the liquid under pressure moves the piston in the desired direction and closes or opens the nozzle or guide passages. Attached to the piston rod is the relay-mechanism G. Immediately the piston begins to move, the further end of the lever H is also moved. and thereby the regulating valve returned to its normal position.

The prompt action of hydraulic governors renders special provisions necessary where the water is taken to the turbines through pipes. The sudden checking of the motion of a large mass of water, usually at a great velocity, produces a pressure far in excess of the normal, which exposes the pipes to the danger of bursting, while at the same time, tending to increase, instead of decreasing the speed of the turbine. Various means are used to prevent this : a by-pass of the same area as the nozzle may be made to open as the latter is closed, the nozzle may be deflected from its normal position to direct the jet away from the wheel, or a shield may be inserted into the jet to deflect the latter from its normal direction. The drawbacks of the deflecting nozzle have already been pointed out. The automatic by-pass and the automatic deflector are generally fitted with a device by means of which their return motion is so slow that the pressure in the pipe line cannot rise enough to endanger it.

The automatic deflector is the most recent device and, combined with the ordinary regulation of nozzles is the most perfect means of keeping the speed constant under difficult conditions. This combination as adopted at Arniberg for a fall of 2,800ft., and also for the 16,000 Pelton wheel at the Loentsch, is shown in Fig. 34, and its action illustrated diagrammatically in Fig. 36. The deflector is a curved shield with a knife edge which in its normal position is tangential to the jet. The governor is connected to the regulating valve (for the nozzle) and the regulating valve 11 (for the deflector), by means of levers ; the lever for the nozzle is provided with an oilbrake to prevent it from moving quickly, while the lever for the deflector is free. If the load on the wheel is changed gradually, the governor will move both the needle and the deflector at the same time, and as the jet becomes reduced in diameter the deflector will remain tangential to it, but as soon as any sudden or great change of load takes place, the deflector will at once cut into the jet and cut off part of the water, while the spear of the nozzle cannot close quickly owing to the oilbrake and a spring connected with the servomotor. The accuracy with which this device acts both on the speed of the Pelton-wheel and on the pressure in the pipe line may be seen from the diagrams, Fig. 37, which

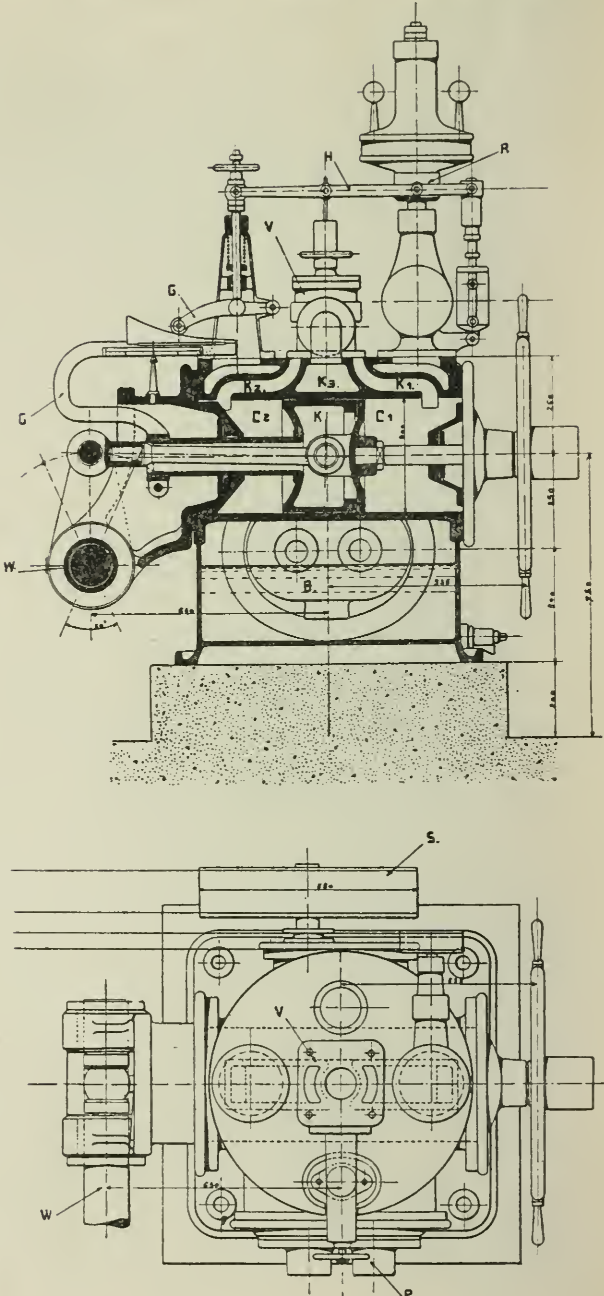


FIG. 35.—OIL PRESSURE GOVERNOR.

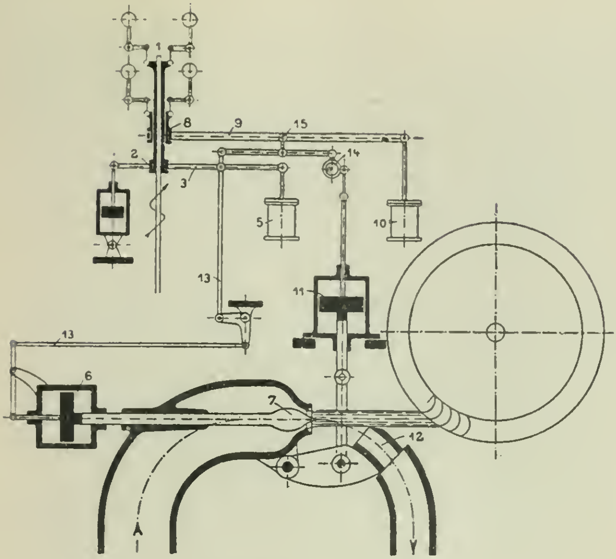


Fig. 36.—Diagram of Automatic Regulator.

were taken at the official tests at Arniberg. It will be noticed that the increase of pressure in the pipe line remains well within 5 per cent. of the normal when the whole 3,000 b.h.p. are suddenly thrown off.

The automatic regulation of water turbines has thus reached a state of perfection and refinement which can hardly be surpassed. The safety of the running parts as well as that of the pipe line is well assured. Yet, in view of the consequences which would follow the bursting of a pipeline under high pressure, a further safety device has been invented and successfully applied. This is an automatic valve, which is fixed to the upper end of a pipeline. Its construction may be seen from Fig. 38. The valve is held in balance by means of a counter-weight fixed on a lever, so that the increase of pressure, produced by the increased velocity which would result from a burst of the pipe, will throw over the counterweight and shut the valve. A standpipe must, of course, be provided of sufficient area to allow air to enter and to keep the pipeline from collapsing if the automatic valve should be suddenly closed.

The Pipeline.—The pipeline is very often by far the largest item in the total capital cost of a power plant using a high fall. To keep the cost low, the diameter of the pipes is taken small and the velocity of the water increased; it must thereby be considered that the loss of head by friction increases practically

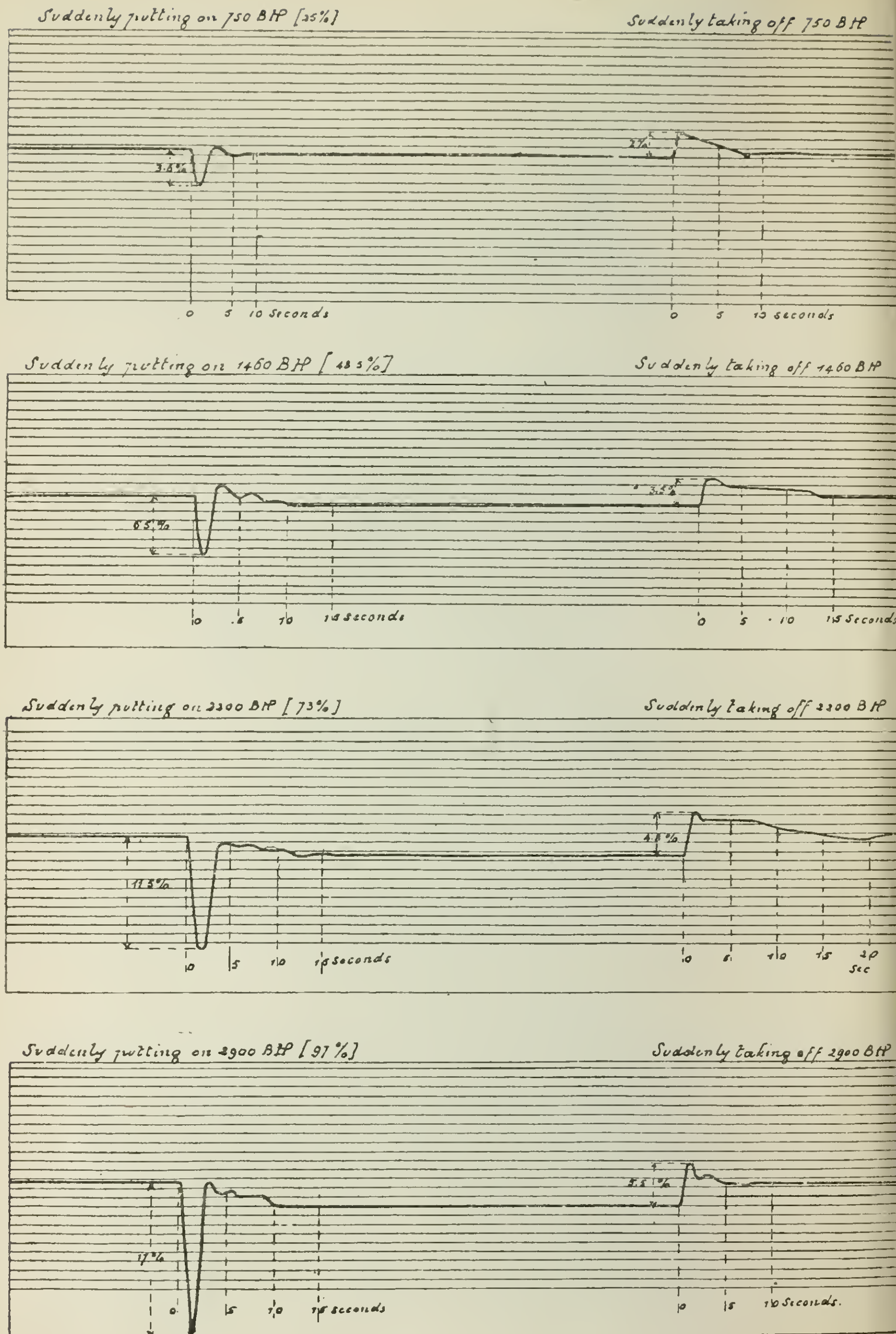


FIG. 37.—TEST CURVES OBTAINED AT ARNIBERG.

as the square of the velocity. The power corresponding to the head lost by friction in the pipeline in many cases represents a considerable capital value, which must be carefully weighed against the extra capital outlay involved in pipes of larger diameter. Generally, the diameter of the pipes is chosen so that the total loss by friction does not exceed 5 per cent. of the total static head. Whereas formerly a velocity of from 3 to 5ft. per second was considered the admissible maximum, we find in modern power installations velocities up to 15ft. in the lower part of the pipelines, where it is desirable to keep the diameter small on account of the thickness of the plates required under high pressure.

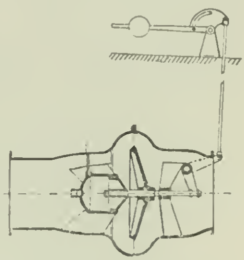


Fig. 38.—Self Closing Valve for Pipe Line.

The most suitable material for pipes is soft mild steel in riveted or welded plates. The pipes are mostly made in lengths at the factory and provided with flanges, but to save cost in transport, the plates are sometimes bent and drilled at the works, and riveted on the site in considerable lengths without flanges. Allowance must, however, be made for expansion and contraction through changes of temperature if the pipes are laid on the surface. For this purpose expansion joints are inserted at suitable distances, or at the bends, and the pipes are laid on saddles to allow movement without deterioration.

In America, where wood of suitable quality is plentiful and cheap, pipe-lines of large diameter and great length have been made of wooden staves tied by hoops, apparently with good results. In recent years pipes of reinforced concrete have also been used for pressures up to 100ft. and proved to be entirely satisfactory. In all probability there will be a further development in this direction.

The Cost of Power.—So far the subject under consideration has been treated from the purely technical point of view, but it must also be considered from the commercial side. In every case where power is required, the question of cost will be considered in the first instance. In comparing water power with other sources of power from this point of view, not the capital outlay alone, but also the annual cost of the power must be taken into account. If the capital cost alone were considered, waterpower would be at a considerable disadvantage as it is often greater than that of other sources of power. It should be the deciding factor only if the available capital is limited or if the amount to be allowed for interest, depreciation and sinking fund is of considerable influence on the annual expense.

If, on the other hand, the annual cost of the power is carefully calculated, it will be found that these are smaller for water-power than those of any other sources of power, even if the capital outlay for the hydraulic power is twice and three times that of say a steam plant. The annual cost of power from various sources are variously given by different authors, but the following figures, taken from the *Electrical Review*, may be considered as fairly correct :

	£	s.	d.
Electrical H.P. per annum from water in Switzerland	1	19	0
Steam in England	4	11	8
Blast furnace gas in Germany	4	1	7
Producer gas in England	5	0	0

The amount given for electrical power from water in Switzerland, viz. : £1 19s. corresponds at 7 per cent. to a capital outlay per H.P. of £27 17s., at which figure water power could certainly be developed in the parts in Great Britain already mentioned.

In water-power plants from $\frac{1}{2}$ to $\frac{3}{4}$ of the total capital is absorbed by permanent structures like dams, canals, pipelines and building work, for the annual maintenance of which 1 per cent. of the capital is quite sufficient. An additional 1 per cent. per annum will cover the depreciation of turbines, labour, maintenance and repairs. Adding 5 per cent. for interest, the total annual cost of water power is 7 per cent. of the capital cost.

In the case of a power generating plant using steam, or gas, or oil, a much greater allowance for depreciation must be made as the machinery is much more liable to deteriorate, and it forms the greater part of the total capital cost ; 5 or 6 per cent. for depreciation on the cost ot the machinery will, therefore, not be too high a figure. Adding to this 5 per cent. for interest and $1\frac{1}{2}$ per cent. for labour involved in handling fuel, ashes and attending to the machinery, the annual cost may amount to $12\frac{1}{2}$ per cent. without the fuel. The cost of fuel varies according to locality and the quality of the installation. Expressed in per cent. of the capital cost, au allowance of $7\frac{1}{2}$ per cent. for fuel is probably a moderate assumption, which makes the total annual expense 20 per cent., or nearly three times that for water power. The capital cost of a water power plant may be about three times that of a steam plant for the same annual cost of power.

The capital cost of hydraulic power installations depends on local conditions and requirements, the size of the plant and the size of the units, but not necessarily on the height of the fall utilized, as is sometimes assumed. There are power plants with high falls involving a larger capital outlay than that of plants

using smaller falls. Figures of the capital cost of a number of existing hydraulic power plants in various countries, published from time to time, show that it varies from £5 to £50 per b.h.p.; in exceptional cases the last figure has even been exceeded, but it is seldom more than £25 or £30 per b.h.p. for fairly large plants. Probably, in the majority of cases it is not more than that of an up-to-date steam plant.

The cost of the turbine proper may be an infinitesimal part or it may be 50 per cent. of the total capital cost, and a calculation of the cost of a turbine installation which is based on the price of the turbine alone will, therefore be absolutely misleading. It is, however, correct to say that the lower the fall the higher the price of the turbine per B.H.P., and, the larger the power of a unit under a given fall, the smaller the cost.

The capital outlay for a hydraulic power plant may be very large and appear prohibitive, yet prove to be a perfectly sound investment. The annual cost per B.H.P. would probably be smaller than that of a steam plant.

Whether a large capital outlay is justified will depend on the load factor. It would certainly not be justified for instance for a plant intended exclusively for the supply of electric light which is only required a few hours each day, but if the power can be applied also for other purposes, for power in factories, for traction, etc., a greater capital outlay is justified. The most favourable conditions are, of course, those where the power is required continuously as in many factories, mines and especially in electro-metallurgical works. These latter practically owe their existence to water power.

The objection is frequently raised against water power that it is irregular and unreliable, requiring a standby, or supplementary plant, at an additional capital outlay, to supply the deficiency during short water time. It has, however, been proved that, provided the load factor is above a certain minimum, the cost per kilowatt hour is not increased and may even be lower. This is borne out by the fact that numerous hydro-electric power stations in Switzerland and elsewhere, have added steamplant to the hydraulic plant with quite satisfactory financial results.

Power plants in industrial centres have mostly a heavy day load, while the night load is very light, or nil. These, if they are situated in a hilly country, can increase the power for the day load by using the power available during the night, otherwise wasted, for raising water to a reservoir at a high level to be used during the day by means of a separate turbine.

An interesting example of such an accumulator plant is that at Schaffhausen, in Switzerland. This is a town with a population of about 20,000 inhabitants and a large industry,

possessing two engineering works, flour mills, rope works, and jute spinning mills, besides some minor industries. It obtains from the River Rhine 3,800 b.h.p. at two separate generating stations, with a fall at each of 15ft. In order to increase this output to satisfy the increased demand, it was decided a few years ago, to put down a high-pressure plant with four units of 1,000 b.h.p. each, of which two are already installed. The surplus power from the low fall plants is transmitted to two electric motors with an output of about 1,000 Kva each. To each of these motors is coupled on one side a high lift centrifugal pump and on the other side a double Francis turbine of 1,000 b.h.p. Each pump is capable of delivering 55·4 cu. ft. per minute to a height of 528ft., running at a speed of 1,450 r.p.m.

The water is delivered into a reservoir 515ft. above the centre of the pumpshaft, capable of holding 2,650,000 cu. ft. through a pipe line 7,100ft. long, with a diameter increasing from 3ft. to 3ft. 4in. This delivery pipe is connected to the pumps as well as to the turbine of each unit. During the night, and on Sundays, the pipe line is used for delivering water into the reservoir and during the day it supplies the turbines, and the electric motors act as generators. This accumulator plant adds 980 b.h.p. during ten hours to the power obtained from the low fall installations. Apparently, the high load factor has in this case justified the expense for the accumulator plant which, owing to the long pipeline, must have been very considerable.

Concessions.—In view of the rapid development of, and the ever increasing demand for water power, since the introduction of the electrical transmission of power, it has become necessary to protect the sometimes conflicting interests involved in flowing water, so much so, that it has been suggested in some countries to make the use of such waters a State monopoly. Whether there is wisdom in such a suggestion the author is not prepared to say, but it might be pointed out that those who intend to utilize water power have as much right to protection as those who make use of rivers for other purposes. It may otherwise happen that schemes which would benefit the population of a district are opposed by riparian owners for no other reason than short-sightedness or prejudice. The application of the laws of expropriation, if extended to water power, would in such cases be a wholesome remedy.

Fishery interests, for instance, are often put forward as a ground for opposing water power schemes and excessive compensation is claimed for alleged damage to the fishery industry. In reality, fishery is not affected at all by the installation of turbines, as long as fish-ladders of proper construction, and suitable gratings in front of the power house, are provided

These afford ample protection against large fish getting into the turbines, while small fish will pass through them absolutely unhurt.

Guarantees.—Orders for turbines are often placed very carelessly and then result in disputes or lawsuits between the purchaser and the turbine maker. Few purchasers realise the practical meaning and value of "efficiency." They are quite satisfied if they obtain the power which they require, regardless of the efficiency. It is quite easy to satisfy such a customer, for a very inferior turbine will give more power than the water-wheel which it is to replace, or a turbine may be supplied which consumes a larger volume of water than the required power warrants. A buyer is apt to take the cheapest turbine offered and seldom considers that the cost of the turbine is only a small item in the total outlay. To make certain that he gets value for his money, he should ask for the statement of a guaranteed "efficiency"—not power—and, where the fall or the water supply, or both, are varying, for definite and legally binding figures for the efficiency at full as well as at part gate.

Unfortunately, the testing of turbines on the site is somewhat troublesome and costly, yet only tests made on site are of real value to the purchaser. A perfectly good turbine may give very poor results if the installation has been badly planned.

It is useful to embody in every contract a clause providing that in case of any doubt as to whether the efficiency guarantee is fulfilled, tests shall be made *in situ*, whereby each party is represented by an engineer experienced in making such tests, the costs to be borne by the losing party. Such a clause is an effective protection against extravagant guarantees of efficiency which are sometimes given to secure a contract but seldom fulfilled. If tests are foreseen in this manner, then it is also necessary to fix on the method to be adopted for measuring the volume of water. If it is to be measured by means of a weir or a sluice gate, the formula to be used and the coefficient for contraction also is to be agreed upon. A difference in the formula or the coefficient for contraction will easily account for a difference in efficiency of

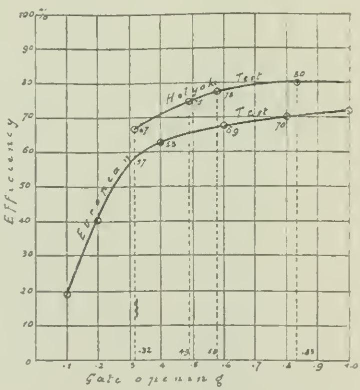


FIG. 39.—BRAKE TEST CURVES OBTAINED ON SAME TURBINE IN U.S.A. AND EUROPE

10 or even 15 per cent. In proof of this, a diagram is given (Fig. 39) showing the results obtained by two experts making separate tests on the same turbine. The variation in the results is entirely due to the different formulæ used in the two sets of tests.

No turbine maker of reputation will refuse to accept conditions such as stated above. Should a small deficiency be established by the tests, then it will be a fair arrangement to stipulate a certain sum to be paid by the contractor to the purchaser for each per cent. deficiency by way of indemnity, the same amount to be paid by the purchaser to the contractor for each per cent. above the guarantee. Such a condition would be quite reasonable up to a difference in the efficiency of say 5 per cent. ; if the efficiency is found to be more than 5 per cent. below the guarantee then the purchaser should be entitled to reject the turbine with the liberty to place his order for another turbine elsewhere. An agreement containing such or similar provisions will save much expense in the Law Courts and assure a smooth and mutually satisfactary execution of the contract.

Testing of Turbines.—This includes the following operations:—

1. The measurement of the fall.
2. The measurement of the volume of water passed through the turbine, and
3. The actual testing by means of a dynamometer, generally a Prony brake, or in hydro-electric installations, by a water resistance or water brake.

Where the water is taken to the turbine through pipes, the pressure head is measured by a pressure-gauge fixed at the height of the centre of a pressure-turbine or at the nozzle of a Pelton wheel some distance from the mouthpiece where the velocity of the water is not very great. This will show whether the calculation of the loss by friction was correct. The height from the nozzle to the tail-water level must, of course, be deducted from the gross fall. The suction head of pressure turbines is best measured by means of a vacuum gauge which would show whether the vacuum is complete or whether there is any leakage of air. In installations with open turbine-chambers the fall is measured by levelling, but it is of advantage to provide indicators permitting the actual head to be read at any time in the engine house where the testing takes place. These indicators consist of floats, surrounded by perforated tubes to assure steadiness. The floats are suspended on cords passing over pulleys, provided at the other end with a counterweight and a pointer which runs along a measured rod divided into inches.

The second operation, the measurement of the water, is the most important, and in most cases also the most difficult operation. For an accurate measurement—and, of course, only

these are of any value—the common method by a floating body is obviously out of question. The methods which give the best guarantee for reliability are the weir measurements for small quantities of water and the Woltmann propeller or current meter for large volumes. Both methods are reliable and accurate if applied with proper care. Of course, all instruments, for whatever purpose they may be required, must be properly tested and their accuracy certified before they are used for testing turbines.

The weir measurement is very delicate, and in order to assure its reliability it is necessary to erect the weir at a place where the water flows to it at a very low velocity so that its surface is perfectly smooth, and that its height above the edge of the weir can be measured with absolute accuracy, for a slight error in that measurement will make an appreciable percentage error in the efficiency. The coefficient of contraction varies with the proportion of the width of the weir to that of the millrace, the height of the edge above the bottom of the race and the height above that edge, measured not less than 7ft. behind the weir. The coefficient is not theoretical but can be found only by experiment. The results obtained by various hydraulicians differ according to the scale on which the experiments have been made, proving the necessity of the utmost care in choosing it. It is desirable, therefore, to erect the weir as near as possible to the dimensions of those for which the coefficient has already been established. The edges where contraction takes place must be sharp and the stream of water as it falls over, must be surrounded by air on all sides. If it adhered to the board of the weir, the volume of water might be as much as 29 per cent. more than that obtained by the formula. It is further of importance to see that all leakage of water at the bottom or on the sides of the weir is absolutely prevented. Much water is sometimes lost through such leakage, which of course has passed through the turbine without being measured, with the result that the efficiency found by the test is higher than the actual efficiency.

For the measurement of the water by a current meter a place must be chosen where the millrace is straight and as far as possible rectangular. The area is divided into a number of sections, the more the better, and the instrument placed in each section for say half a minute. This will, of course, require a considerable length of time in a millrace of large area and it is necessary to see that during the whole time the turbine is run with the same gate opening and at a uniform speed. As the velocity of the water may vary at the same spot from various causes, a repetition of the measurement is desirable. If the measurement by current meter were taken at a bend of the millrace, it might happen that the velocity of the water is so small

on the concave side that the instrument would not indicate, or the water might even flow backwards and form a whirl, which obviously would make the whole measurement illusory.

The mechanical device by which the power of a motor is measured, is generally known as the "Prony Brake." By this brake the power produced by the motor is absorbed by friction between a pulley and some wooden blocks which are pressed against it. The formula by which the output is found, is :—

$$p = \frac{L\pi}{30 \times 550} \cdot nW$$

in which "L" denotes the length of the lever in feet, "n" the number of revolutions per minute, and, "W" the weight in lb. acting at the end of the lever to keep it in balance. As the length of the lever will be the same for a series of tests, the factor $\frac{L\pi}{30 \times 550}$ will be constant for this series and we have only to note the weight and speed for each test.

Simple as the operation appears to be at first sight, there are many difficulties to overcome if the tests are to be reliable. The turbines are often placed so awkwardly that the placing of the brake is by no means easy. Then it is of the greatest importance to keep the brake steady while a test is proceeding. To prevent the brake from catching fire, a very frequent occurrence, a jet of water, or better of a soap solution, is directed on to the brake and this jet must be very even to assure a nice balancing of the lever. It is best, where possible, to use a specially constructed brake pulley which can be kept cool by a separate jet of water applied to the inner surface of the rim, while the outer face, where the friction takes place, is lubricated independently by means of oil. Of course, the feed of the lubricant must be very regular.

According to the disposition of the turbine and the turbine house, the brake may be fixed direct on the turbine shaft, whether it is vertical or horizontal, and the weight necessary to balance the power may be measured direct by letting the end of the lever press on the table of a weighing machine, or the weight may be suspended on a cord passing over one or more sheaves. In the latter case, the stiffness of the cord, and the friction on the bearings which carry the pulleys form a factor of uncertainty, and experts will have to determine what allowance should fairly be made for such losses.

The same also applies where the brake must be fixed on a countershaft, driven by intermediate gearing. It is in such cases extremely difficult to arrive at a safe and convincing conclusion of the efficiency of the motor proper. A well arranged set of wheel gear will absorb very little power in itself and the power absorbed by it may be very much exaggerated ; on the other

hand, a badly proportioned set of gear will absorb an amount of power which it is impossible to ascertain with accuracy. It will be seen from this that the preparations for the testing of a turbine, as well as the testing itself, require a good deal of time and there may be a tendency to get them over as quickly as possible, giving superficiality an opportunity to creep in and, eventually, to destroy the whole object and value of the tests. A complete test should consist of a series of records, taken every few minutes at the same speed and the same load on the brake while the latter is absolutely steady, with the same gate opening. Records should also to be taken for the same gate opening at different speeds, and repeated for different gate-openings. These records are then tabulated, or recorded on a diagram. The latter method has the advantage that it will at once show errors in any of the measurements, of which there is always a possibility, and which can then be eliminated by a repetition of the test.

The paper, though somewhat lengthy, has left many points untouched which, the author hopes, will induce discussion and thus add to its value as a contribution to the literature on the subject of water power.

Discussion.

The President said that he was sure that those present had all listened with extreme pleasure to the paper, and had viewed with interest the slides which the author had shewn on the screen. He knew that it was their wish that he should propose to the author a hearty vote of thanks for the contribution which he had made.

The vote of thanks was carried by acclamation.

Mr. Holroyd Smith said that the paper gave a large amount of very useful information without causing the members to rack their heads with formulæ which nobody understood. It was a good many years since he had any real active practice in reference to water power, but he had a pleasant recollection that the work which he then did was very successful. The case with which he was concerned was that of some large paper mills in Yorkshire where there was a high fall and three water wheels in succession. Those water wheels had to be taken out and a turbine substituted. He was afraid that the turbine used then would be rather amusing to the author. Anyhow it was most effective in its work. It earned quite a good reputation in the district, and he had to attend to all the mills further down the stream to improve their water power.

There was a little point which the author had not mentioned, which, in his opinion, was of great importance in dealing with the utilisation of water, and that was the prevention of air being carried down with the supply of the water to the turbine. That was a point which he found was often overlooked by those who were putting turbines down the stream to which he had just referred. He attributed a large part of the success of the installation which he had undertaken to the fact that he provided very large flumes at the intake of the water, so that any air that tended to come in had plenty of time to bubble up before the water entered and was carried down the main pipe. He was also liberal in regard to the diameter of the pipes down to the turbine. That was a point of such importance that he was taking the opportunity of stating what his practice was so that other people might profit by it. He would say, " Do not neglect the area of the intake of water to the water turbine."

There was another point which he felt was a practical one which had not been mentioned in the paper. That was with reference to taking sufficient care to prevent debris and leaves of trees getting down into the pipe. He found in figures 20, 21, 23, 24 and 25 an error which he had had to protest against over and over again, namely, the slope of the screens shown was the usual 45 degrees. He had found it advisable to make the angle of the screen with the bottom of the channel about 25 degrees, so that the leaves and the stuff that came could be easily scraped up over the top and carried away. This was only a little detail, but such little details counted.

On page 270 the author spoke of testing by means of the Prony brake. If by Prony brake Mr. Steiger meant the primitive contrivance that usually went by that name, then if there was one thing connected with the question of testing power that he (the speaker) detested and abominated more than another it was the Prony brake. He thought it the most risky and unsatisfactory means of testing the power that could well be conceived. He had a vivid recollection of the last occasion when he used the Prony brake for testing water power in Cornwall. When they got it into operation everybody fled except himself, and he had to find a change of clothes very soon afterwards. He would suggest that instead of using the Prony brake, or even the better sort of absorption dynamometer, they should use a transmission dynamometer. He wondered why so experienced a gentleman as the reader of the paper had not given attention to a transmission dynamometer for the purpose. He should be very pleased to have a little conversation with him afterwards, when he thought he could suggest a transmission dynamometer which would save him a lot of the trouble caused by the uncertainty and unreliability of the Prony brake.

He would like to ask a question in order to get as much information as possible and clear his brain of any error or hallucination that might have been hovering there for years. Ten or fifteen years ago Professor Walker showed to several people an idea sent to this country from Canada for the utilisation of water power which was so different from anything else that he would like to know what Mr. Steiger thought of it. The water was caused to go down a number of pipes with trumpet-shaped mouths, carrying the air with it. The air was sucked in in the same way as when one pulled the plug of a bath. They all knew the noise that was then made. The air in the case he referred to was drawn down the pipes until it reached a large tank at the bottom of a deep pit, and there it was liberated into a big chamber, obtaining the pressure due to the fall of the water. The water came up from the bottom of the tank, and flowed out again at the lower surface level, and the air was taken from the top of the chamber and used for driving air engines in a factory. Probably Mr. Steiger knew the place in Canada where that was actually done. He would like to know what the real fallacy in the operation was, because, as far as he knew, it had never been adopted in this country. If it was a good idea why had it not been put into effect ? The opportunity of transmission through a lot of little engines planted round works made it a very useful thing. The idea was highly spoken of at the time, and some of those present might remember it.

Mr. W. B. Esson said that whenever he heard Mr. Steiger read a paper he learned a good deal from it, and the present paper was no exception. He should like to make a few observations on brake tests. Mr. Steiger talked about hydraulic brakes, but were such brakes constructed to test turbines of 10,000 horse-power ? He had never heard of them. It seemed to him a very difficult thing to test turbines at all with a dynamometer, and it was very unsatisfactory, as Mr. Holroyd Smith had pointed out. On pp. 267-8 of the paper the author referred to a turbine tested by an expert in Europe and another expert in America, and it appeared that the difference at full load was as much as 8 per cent., while the difference at 80 per cent. of full load was 10 per cent. This showed that it was a very difficult operation. He thought the only way of dealing with turbines was to test them electrically. If they had a turbine driving an electric generator the testing operation became perfectly simple so far as the power yielded was concerned. Speaking for himself, he would never split a contract for a turbine and generator between the makers of each, but would make the contract either with the turbine maker or with the generator maker so that there would be no divided responsibility. The efficiency that the contractor would

have to guarantee would be the electric power produced for a given fall and quantity of water. They could not measure the water except in the way that Mr. Steiger had described, and here again there was great difficulty. The result was a matter of much uncertainty, and, as had been shown, the efficiency came out differently according to the formulæ used.

He would like to mention that often it was far less expensive to put in a Pelton wheel than to put in a turbine, not so much on account of the first cost as on account of the wearing out of the buckets. He remembered that the buckets of the Pelton wheels that were installed at the Burma Ruby Mines some years ago wore out in a very short time owing to the water being loaded with ruby earth ; under the circumstances turbines would have been useless, as their buckets are dear while Pelton buckets are cheap.

With reference to the efficiency of turbine wheels it was unimportant, generally speaking, unless there was a shortage of water, to have a high efficiency at half gate or partial gate. They wanted to get the maximum power out of the water as a rule, but for any intermediate power, unless they were short of water, it did not matter very much. The thing was to get the highest efficiency at the highest power.

Mr. C. T. A. Hanssen said that the substitution of turbines for water wheels in this country seemed to be somewhat difficult because the compensation generally demanded by the owners of the water power was so great that it swallowed the whole of the profit due to the saving of coal. He had had a little to do with some compensation cases in Wales, where there were some falls developing about 12 H.P., and by diverting some of the water about 4 H.P. was taken away. The idea of compensation was that a petrol engine of 12 H.P. should be put down and then a money payment equivalent to the capitalised value of the petrol used should be allowed. Instead of being content with 4 H.P. additional, the owners wanted the whole of the 12 H.P., because they said that the remainder was no good for driving their factory. They did not get the compensation which they asked for. They were offered simply a money payment down, and they had to accept it. If they could have done it they would have driven a very hard bargain indeed. Speaking generally, he thought that all water power suffered a great deal from agricultural drainage. As soon as agricultural drains were put in in a district the greater part of the water flowed away during a short period of maximum rainfall, and during the rest of the year there was very little flow left to supply the water power or drive the turbine. He was afraid that that difficulty could never be obviated except in mountainous districts where there was no cultivation of the land. As the author said, afforestation in mountainous districts

was a very important thing, and he hoped that the Government would take notice of that, and fulfil their promises to plant forests on the mountains and in unfertile districts, which were natural collecting grounds for all water power that might be available in this country. There was a very large quantity of water in some of the Welsh mountains, but the great point seemed to be that the compensation demanded was excessive and that it was not as a rule uniformly distributed over the whole year. It came with a rush in spring and autumn, but during the summer months there was hardly any, and that fact made a water wheel almost as expensive as a steam engine. The great thing was to have the water all the year round and either to use it day and night or to be able to store it in large reservoirs during the night. If that could be done they could get water power at a very low price. Mr. Steiger spoke of £1 19s. per H.P. year, but he supposed that the figure referred to power used for part of the time only. It had been found possible, in countries where compensation for water power was small, to get it as low as £1 per H.P. year. That meant working continuously day and night all the year round. If it could be got at that price a great deal could be done in the way of chemical engineering, but if it was more expensive than that it did not seem remunerative to use it for making nitrates and other such products from the atmosphere, which had to be produced in large quantities at a comparatively low cost. Mr. Steiger did not say how he arrived at the figure of £1 19s. Patentees for nitrogen and so on stipulated that the cost of power must not be higher than £1 per H.P. year. There were several large installations in Norway, and he thought in other places too, where the cost per H.P. year had actually been below £1 when working all the year round, day and night.

Mr. Humphrey M. Morgans said that the way in which the harnessing of water power had developed was very fascinating. The plant units grew larger and larger. In electrical and steam plant the same tendency was to be noted. Efforts were constantly being made to get the most horse-power out of every pound of material put into a machine, and new and stronger materials had to be developed.

For governing Pelton wheels the designer needed to know the profile and the proposed size of the pipe line, so that he would know what inertia there was in the moving water in the pipeline. The inertia of the rotating parts made a difference on the speed changes when changes of load occurred. He wanted to know whether it was the practice, with a good oil pressure governor in use, to put an automatic relief valve at the bottom of the pipe line or to rely absolutely on the oil pressure governor to keep the pressure rise in the pipe line within permissible

limits. It was a marvellous thing that they should be able to knock off the whole of a big load and get a permanent speed change of only 9 per cent. and an increase in pressure in the pipe line of not more than 5 per cent.

As regards pipe lines Mr. Steiger said that speeds up to 15ft. per second were allowed in high pressure pipe lines, chiefly on account of the difficulty of getting strong enough pipes for a lower velocity. It would be difficult to keep the friction loss within 5 per cent. at such high speeds unless big pipes were used.

He would suggest that it might be a useful addition to the paper to put in one or more reliable formulæ for obtaining the frictional loss in the pipe line. In the *Engineering and Mining Journal* of the 7th December, 1912, there were half a dozen formulæ given, also a set of curves giving the frictional loss in pipes up to 12 ins. bore based on the average of the formulæ.

The speed of an ungoverned Pelton wheel might run up to 80 per cent. in excess of normal speed on the load falling right off, so that a generator on the same shaft as the Pelton wheel ought to be capable of an excess speed of 80 per cent., and that needed particularly to be made known to the generator maker when the order was placed.

On the question of water brakes, mention had not been made of what was really the standard water brake nowadays, namely, that made by Messrs. Heenan & Froude, of Worcester. He believed that Messrs. Sulzer Brothers, in Switzerland, have a brake of this make capable of absorbing 4,000 horse power continuously.

Mr. Esson said that he would like the author to tell them in his reply whether the buckets which he had shown on the screen, which were so worn out, were steel or cast iron buckets.

The Author : Cast iron.

Mr. A. R. Tattersall said that he thought that the main point was that every water power scheme appeared to require to be considered as to its variable water quantity and the fall, and that a certain turbine was not suitable for every position. One must study the life-history, so to speak, the particular location and the varying quantities of water at different times of the year and the height of the tailwater, to get the best type of turbine to put in. He remembered meeting Mr. Steiger about twenty years ago on a water power problem in the eastern counties. The board of directors had received nine turbine estimates, and they asked him (the speaker) if he knew anything about turbines. He said that he did not know very much but he knew a man who did. That gentleman was called in and he threw over the whole of the nine estimates and specifications and

said that they were all wrong and that, having regard to the varying quantity of water and the varying height, he thought there should be a turbine which would have two concentric rows of buckets, so that when the water varied in quantity and there was a maximum height and a minimum quantity of water, it would give as good results as when there was a maximum quantity of water and very little fall. When the board of directors put in the particular type of turbine which the author recommended, they found that they could drive their mill with only 18 inches of water fall, which they had never expected to be able to do, and had never done before.

When the author left the technical side of the paper and went to the commercial side he was rather at fault. He had taken the *Electrical Review* as his authority for the cost of 1 19s. 0d. per H.P. year as against £5 for producer gas. He thought that there were producer gas makers who would tell them that they could get 10 horse power hours for a penny, and running for 140 hours a week and fifty weeks a year it only cost £2 18s. per annum, reckoning coal at 30s. a ton.

He was very much obliged indeed to Mr. Steiger for the information that he had given. He would like to ask him at what height he would stop using other types of turbine and put in a Pelton wheel. He once put in a Pelton wheel in Spain of which he had a very unpleasant recollection. It did not turn out good enough and it had to be replaced by another type. He thought that there must be some limit to the fall at which a Pelton wheel should be introduced. There should be a certain height for it ; it would not do at low falls. He would like to know whether there was any rule on the subject.

Mr. Harry Geen said that he had had an opportunity of testing some low pressure Pelton wheels some years ago. He did not know what Mr. Steiger's opinion might be, but he found 35 ft. the limit of head at which it was possible to get good results, and that at anything less than 35 ft. it was very inefficient. If his memory was right, at 35 ft. there was an efficiency of only about 62 per cent. He would like to ask Mr. Steiger when it became desirable to have a Pelton wheel instead of a turbine. After various investigations he had come to the conclusion that for variable flows and low variable flows a Pelton wheel above the 35 ft. limit was a better motor than a turbine, because they might have three or four nozzles, as had been shown that evening, and when they had a small flow of water they might use one or two nozzles and get full efficiency out of them, whereas one did not get full efficiency out of half gate or third gate in the case of a turbine.

He thought that Mr. Steiger knew the installation at the electrical works at Lynton in North Devon. The result there was that by changing the old turbine wheel of 62 per cent. efficiency and putting in a turbine wheel under Mr. Steiger's advice, the efficiency then (and he believed now) measured electrically and not measured in any haphazard way, was 84 per cent. Mr. Steiger recommended pumping during the day. Seeing that electrical current was required more in the evening and at night, the plan which had been adopted with very good results at Lynton had been to pump during the day to a height of 800 ft. above the electrical station into a small circular reservoir, using the stored water at night with the Pelton wheels to help the turbine. That was an installation which, he thought, had not been copied anywhere else in England.

He was afraid that part of the difficulty, as previous speakers had said, was the question of payment to riparian owners and to people who owned water rights. As regarded the figure of £1 19s. per H.P. year, his small experience of Switzerland was that there were no long water courses, or very few, to pay for. One found there a vertical fall of water with only a straight line of pipe from the top flume down to the water generator. That state of things was not very often found in England. To give a simple illustration, some years ago he was interested in an electrical installation in a small town where the owners of the water asked for £100 per annum for its use, and the right to cut through some ordinary moorland for a water course to take the water for the turbine. It meant cutting a water course about a mile and a half long. The capital cost of it, with the payment of £100 per annum, was a first charge on the use of the water. That and the cost of the installation killed the whole scheme. He was convinced that many installations would be put in in England but for excessive greediness on the part of landowners, and excessive cost in compensation.

Mr. Alfred S. E. Ackermann said with regard to transmission dynamometers he knew that Mr. Holroyd Smith was the inventor of one, but he had forgotten the details as it was many years since it was described to him. The trouble with transmission dynamometers was that they could not be calibrated very easily whereas the Prony brake could be. If he were called in to test a plant with a transmission dynamometer, it would probably take him the best part of two or three days before he could determine what the constant of the brake was, whereas in the case of a Prony brake that could be ascertained in half an hour. When it came to water turbines of 20,000 horse power, it was probable there was no other way than to take the over-all efficiency of the turbine and dynamo, and if they wanted to know the turbine

efficiency separately, it would be necessary to predetermine the efficiency of the dynamo, or rather of two sister dynamos, by applying the Hopkinson test to them.

Mr. Holroyd Smith said the speaker was assuming that hydraulic power was used only in combination with electric power, but it was sometimes used without.

Mr. Ackermann said that that was so, for most of the big hydraulic power stations were hydro-electric.

Mr. Holroyd Smith had mentioned the compression of air by falling water ; that was known as the Taylor air-compressor. A large Taylor air-compressor was installed at Magog near Montreal, Canada, and had been reported on favourably by his former chief, Prof. Unwin, F.R.S., M.I.C.E., and by Mr. W. G. Walker, A.M.I.C.E., in 1897. It developed about 150 H.P. and compressed to 52 lb. per sq. in. by gauge. Mr. W. G. Walker had a large working model near by in Westminster some years ago and it might be there still. It was curious that the air so compressed was dry.

Mr. Norman Scorgie said that Mr. Geen's remarks about riparian owners might to some extent indicate the reason why there were not more water power installations in this country. One thing which struck him when he was journeying about two years ago in the Austrian Tyrol, was that nearly every little village of only 400 or 500 inhabitants had its own water power electric light installation, no doubt from the mountainous torrents which were everywhere apparent. On the Dolomites the little villages dotted here and there always had electric light. He was away from railway districts because he was motoring at the time. Noticing the state of things he made enquiries, and one and all told him that they had a little water power installation. He was afraid that as regards Scotland, Ireland, and Wales (he could speak more particularly for Scotland) there were very few streams that Mr. Steiger would find available for water power installation. He remembered many years ago finding an installation in Fort William in Inverness-shire, from Glen Nevis. Water power installation for electric light purposes was a great surprise to the inhabitants, and it was one of the curiosities of the place. People from the hills around used to come to see it. An old lady from the hills went to a grocer's and found nice little electric lamps glowing there. She asked what it was that gave such a beautiful light and the grocer told her " current." She said, " I will have a pound of those, and if I cannot make a light I can make the old man a pudding."

Reply.

The author said in reply to Mr. Holroyd Smith that air must in all circumstances be prevented from getting into the turbine. The mouth of a pipe line or the turbine itself must be placed so far below the surface of the water that no whirl could form and no air be drawn in. The entrance of air into a turbine produced irregular motion and a reduction of efficiency, which was especially great in pressure turbines. In the case of low-fall turbine installations there was a tendency, in order to save excavation, to place the turbine too near the surface of the water to provide sufficient area for the discharge of the water from the turbine. The result was that a whirl formed above the wheel, and air passed to it, reducing the efficiency at once by 15 to 20%.

Mr. Holroyd Smith was quite right in what he said about the angle of the screen in the figures, which must not be taken as showing exactly what would be required in every case. Where one could be sure that the water was fairly free from weeds, etc., an angle of 45° might be adopted with perfect safety, but he had very often seen almost vertical screens in this country. That was bad practice, because weeds, pieces of wood, and so on stuck in the screen and at once reduced the fall by a few inches. Whereever it was possible to take a flatter angle, say 40° or 30° with the horizontal it was certainly preferable, and was simply a matter of expense. With a flat angle the weeds were carried to the top of the grating, leaving the spaces between the bars of the grating entirely free. He was reminded of a visit to some paper mills in Scotland where a turbine had given a lot of trouble, the alleged cause being that " the turbine gets choked." In each case the turbine was a Macadam turbine. These wheels were generally subdivided into a number of stages with orifices of small area, which were bound to get choked unless a proper grating were placed in front of it. Generally the space between the bars of a grating should not be more than three-quarters of the narrowest dimensions of an orifice. In one case a turbine of 120 H.P. had been removed owing to the trouble it gave on this account. At that time they paid 4s. for a ton of coal, now the price will be quite 10s., and they would have effected a considerable saving by having installed a new and more suitable turbine.

He should be very glad to know more of Mr. Holroyd Smith's transmission dynamometer. So far he had always used a Prony brake, but where the power was used for driving a dynamo, the efficiency of which is generally tested at the maker's works before delivery, the power actually developed was preferably determined by the reading of the ammeter and voltmeter.

Mr. Esson had asked how a 10,000 H.P. turbine could be tested. The efficiency of the generator being known, it would simply be a question of measuring the fall and volume of water.

In the measurement of large volumes of water by the most accurate methods, either by a current meter or by a weir, there may always be a difference of from 2 to 5% between the result of the measurement and the actual volume. It therefore seemed absurd, in view of the friction and other losses, to claim efficiencies of 90 per cent. and upwards.

Mr. Esson had mentioned a Pelton wheel, the buckets of which showed excessive wear and had to be renewed every few weeks. With high falls, such as are mostly utilised by Pelton wheels, it was important to provide for pure water and to allow sand or grit to settle before the water reached the wheel. In Cornwall he had heard complaints of the buckets or vanes wearing out very quickly, but this was no doubt due to the presence of sand in the water, or to the unsuitable design or material of the buckets. Bronze was the best material for buckets exposed to the action of sand.

Mr. Esson had said that a turbine should give its best efficiency at full gate, and that it mattered little if the efficiency were low at part gate. That was correct if it were a question of reducing the gate opening to suit a varying load for short periods, but if, as in most cases the water supply was diminished during long periods, it was actually of the greatest importance that the efficiency should also be high at part gate, otherwise the loss of revenue from the plant might be very considerable.

Mr. Geen had referred to the difficulty which sometimes arose when water was taken away from a water course which supplied a water power plant. That was sometimes a serious matter because if the efficiency of the motor was inferior at part gate, the power would not only be reduced in proportion to the water abstracted, but would be further diminished on account of the inferior efficiency. He had once to make an investigation and give evidence in a case where a waterwheel was used to drive some light machinery in a flour mill. A neighbour asked and received permission from the miller to lay one or two pipes to take water from the head-race to some tanks for trout-rearing, but actually ten pipes had been laid, and so much water abstracted that the wheel was no longer capable of driving the machinery, and had become useless. The lawsuit ended in favour of the miller.

The cost of an electrical H.P. from water power in Switzerland had been given as £1 19s. He believed this figure was based on a 12 hours day and 300 working days per annum, but such figures have only a relative value, as the annual cost of power obviously varied in every case.

In reply to Mr. H. Morgans, pressure regulators were necessary, particularly in connection with long pipe lines. If, in consequence of suddenly taking off load, the gate of a turbine were rapidly closed, the pipe line would be exposed to the danger

of bursting, unless means were adopted to prevent the water hammer which follows a sudden check in the motion of a large column of water, and this could be accomplished either by a pressure regulator or by an automatic or safety valve, but not by both. To secure a good regulation, an extra fly-wheel was required if sufficient momentum could not be obtained from the rotor of the generator.

Mr. Tattersall had stated that the cost of power from producer gas given in the paper was too high. It was quite possible that in some cases such power might be produced at £2 10s., and did not know where the figures given in the *Electrical Review* came from, but thought they might be considered accurate. If power could be produced more cheaply, all the better, but the allowance for maintenance and depreciation should not be understated.

He had been asked what was the lowest fall which could be utilised by a Pelton wheel. The question was somewhat vague ; it depended on the power which was required. A Pelton wheel can be used for a fall of 15 ft. if not more than ½ or 1 H.P. was to be developed, but it was seldom that a Pelton wheel was used for heads of less than 30 ft. If the power required, or the volume of water were too large for a single Pelton wheel and too small for a Francis turbine, then a Girard or a tangential turbine would be better than putting two or more Peltons on one shaft, as had occasionally been suggested. For this reason he had pointed out in the paper, that it was unfortunate that the Francis turbine and the Pelton wheel had become the fashion, to the exclusion of other good types. There would always be cases where none of the now fashionable types would answer all requirements satisfactorily. A case in point was the temporary installation at Kinlochleven. There the problem was to supply a motor capable of developing 3,000 h.p. under a fall of 380 ft., and to run it at a speed of 300 r.p.m. Tenders were received for a Francis turbine, a double Pelton-wheel and a single Pelton wheel with six nozzles. The latter was the best solution of all ; the Francis turbine certainly could not have been efficient, and the double Pelton wheel would have been very costly. Another solution, which would have been preferable to either the Francis or the double Pelton wheel,would have been a Girard turbine or a tangential wheel with horizontal shaft.

He wished to thank the Society for having given him the opportunity to read his paper, which was intended to give useful information to all who had to do with water power, and he also wished to thank Messrs. Theodore Bell & Co., of Kriens, Switzerland, for the diagrams illustrating some of their turbine installations described in the paper.

ANNUAL GENERAL MEETING.

The Sixth Annual General Meeting of the Society was held at the Offices, 17, Victoria Street, Westminster, on Monday, December 13th, 1915, at 5.30 p.m., the President, Mr. Norman Scorgie, being in the Chair.

The notice convening the meeting was read.

The Secretary read the Report of the Scrutineers on the result of the Postal Ballot for the election of the Council and Honorary Officers for the year 1916 (see page 285). The awards of premiums made by the Council in respect of papers published in the Journal during 1915 were announced (see page 285).

The Report of the Council for 1915 was read and adopted (see next page).

Messrs. Begbie, Robinson & Cox, Chartered Accountants, were re-elected as the Auditors of the Society for the ensuing year, on the motion of Mr. F. L. Ball, seconded by Mr. Burnard Geen.

A vote of thanks to the Scrutineers, Messrs. G. Noble Fell and H. Laurence Butler, for their services in connection with the Postal Ballot for the election of the Council for 1916 was proposed by Mr. Percy Griffith, seconded by Mr. Henry C. Adams and carried unanimously.

The meeting closed at 5.45 p.m.

REPORT OF THE COUNCIL FOR THE YEAR 1915.

In presenting their Sixth Annual Report since the amalgamation and incorporation of the constituent societies the Council have to state that the membership at this date is as follows :—

Hon. Fellows	23
Fellows	55
Members	310
Associate Members	185
Associates	14
Total	587
Affiliated Student Members...	83

Although every sphere of work is affected by the European War the Society has, nevertheless, been able to continue its activities effectively during the past year.

About fifty members are on Active Service with the Allied Forces, and many more are engaged on miscellaneous War work, as befits engineers when the results of the War depend so largely on engineering science.

The Council have to record with deep regret the deaths of Sir Andrew Noble and Sir Henry Roscoe (Hon. Fellows), Professor Henry Robinson (Fellow), Messrs. Thos. Buckley, L. H. Moorsom, and C. E. Stretton (Members), and Messrs. W. H. Brown and F. Bather Scott (Associate Members).

Meetings.

Six Ordinary Meetings have been held during the year and there have been 10 meetings of the Council and 37 meetings of the various Committees.

Visits.

Visits were made during the Summer vacation to works of engineering interest as follows :—

June 17th.—Messrs. Edison & Swan's Incandescent Lamp and Electrical Engineering Works, Ponder's End.

July 13th.—Messrs. Napier's Motor Car Works, Acton.

September 15th.—Messrs. Cassell's Printing Works, La Belle Sauvage, E.C.

Finance.

The Balance Sheet and Income and Expenditure Account for the year 1914, duly audited by Messrs. Begbie, Robinson & Cox, Chartered Accountants, were published in the Journal for March, 1915, and sent to all members of the Society. The financial position of the Society is satisfactory.

PAPERS AND PREMIUMS.

Mr. Norman Scorgie, M.Inst.C.E., delivered his Presidential Address on February 1st, and dealt broadly with the subject of Municipal Engineering.

The thanks of the Society are cordially offered to the following authors who have contributed papers for reading at meetings or for publication in the Journal during the year :—

- A. S. E. ACKERMANN : "Utilisation of Solar Energy."
- ARTHUR H. BARKER : "Future Developments in Heating and Ventilation."
- CAPT. R. W. A. BREWER : "Running costs of Motor Vehicles."
- PERCY GRIFFITH : "Lecture on Public Water Supplies."
- FRANK GROVE : "Main Roads, Past and Present."
- L. S. SPIRO : "Lighthouse Design and Construction."
- A. STEIGER : "The Modern Development of Water Power."
- SYDNEY G. TURNER : "Law and Engineering: Some points of Contact."
- A. E. WHITCHER : "Reconstruction of a Country Gas Works."

The Council have awarded Premiums to the following :—

The President's Gold Medal to Mr. ARTHUR H. BARKER.
The Bessemer Prize, value £5 5s., to Mr. A. STEIGER.
A Society's premium value £3 3s., to Mr. SYDNEY G. TURNER.
A Society's premium, value £2 2s., to Mr. FRANK GROVE.

The Council would be glad if members intending to offer papers during the coming year, or having engineering friends who would offer papers, will communicate with the Secretary as early as possible, giving the title of the proposed communication and indicating its scope.

COUNCIL AND OFFICERS FOR 1916.

The result of the postal ballot for the election of Council and Honorary Officers for 1916 is as follows :—

President : PERCY GRIFFITH.

Vice-Presidents : HENRY C. ADAMS, W. B. ESSON, W. N. TWELVETREES.

Members of Council : HENRY ADAMS, C. T. WALROND, F. L. BALL, BURNARD GEEN, The Rt. Hon. LORD HEADLEY, F. H. HUMMEL, T. J. GUERITTE, B. H. M. HEWETT, G. A. BECKS, G. O. CASE.

Associate Member of Council : C. E. MAY.

Hon. Secretary and Hon. Treasurer : D. B. BUTLER.

The thanks of the Society are due to the Scrutineers of the ballot lists, Messrs. G. Noble Fell and H. Laurence Butler, for their services.

Professional Status.

The work referred to in the Council's report for the year 1914, has been continued during the past year and considerable progress has been made towards the preparation of a comprehensive scheme dealing with the professional qualifications, fees, and etiquette of Consulting Engineers. Consideration is also being given to the position of salaried engineering officials, particularly those employed by Municipal and similar bodies. The work undertaken has proved very complex and arduous, and the Council will always be glad to receive from members information or suggestions likely to assist them in accomplishing their object, namely, the improvement of the status of professional engineers of all classes.

Appointments Register.

Forty-one applications for assistants have been received during the year, for which 209 candidates have been put forward, 26 of whom are known to have been appointed.

The Council specially ask members to notify the Secretary of any engineering vacancies that come to their knowledge, and to make use of the Register when requiring assistants.

Library.

A number of new books have been added to the Library and are available for the use of members on the conditions stated in by-law 22. Reviews of all new books received have been published in the Journal.

Membership.

Members are asked to bring the advantages of the Society to the notice of their engineering friends and to propose suitable candidates in order that the membership roll may show a decided increase during the coming year. It is to the advantage of individual members that the Society should be as large and influential as possible, and each one is asked to propose at least one new member. The necessary forms of application may be obtained from the Secretary.

The Council hope that more Members will qualify for Fellowship by examination. The examination syllabus provides for engineers in any particular branch of practice, and is of such a character that the possession of an examination certificate cannot fail to bring credit to the holder as evidence of a competent knowledge.

17, Victoria Street, Westminster.
13*th December*, 1915.

INDEX TO TRANSACTIONS, 1910-15.

The date following each title indicates the year of publication, and the page reference is to the volume of Transactions for that year.

NOTE.—A complete index to the Transactions of the old Society of Engineers will be found in the last volume published by that Society, and the volumes of Transactions of the Civil and Mechanical Engineers' Society are also indexed.